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14. ABSTRACT

Augmented reality technologies have reached a stage where commercially viable systems will soon enter the consumer market. These technologies merge virtual content with a user's real-world perceptual experiences. The following paper argues that AR systems will in fact serve as the next revolution in information technologies and as such it should be leveraged by the U.S. military to maintain its relative information superiority advantages. The use of AR systems at the tactical level and operational level would provide each branch of service marked improvements in a variety of tasks. Furthermore, the use of AR systems by operational leaders and their staffs would provide expanded abilities to understand complex operating environments and direct tactical forces.
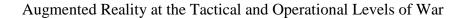
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Augmented Reality at the Tactical and Operational Levels of War

By Maj. Ryan J. Kenny

24 October 2015

Contents

Author's Note

Executive Summary

Augmented reality (AR) systems have been used for years, but due to their cost and complexity, most AR systems were developed for very specific applications. Soon, low-cost, adaptive AR systems will enter the consumer market place. As commercially viable AR systems become available, many market analysts predict that AR systems will become regular features of most people's daily lives and work environments. Just as the regular use of personal computers and smartphones altered human behaviors the habitual use of AR systems will also transform how people interact with their environments and each other.

Augmented reality systems merge virtual content with a user's real-world perceptual experiences. Information from one's surroundings is captured by AR systems through a multitude of sensors incorporated into AR devices. Various AR applications then process this captured data so as to present AR users with enhancing information in real-time. This enhancing information is typically presented by means of an optical display device worn as glasses, goggles, or a visor. Depending on the type of AR display device this information can be presented in either two or three dimensions and can either float over a user's perceptual field-of-view or be digitally anchored so as to appear like a real object for the AR user to interact with.

Continuous access to AR content has the potential to affect how AR users think, learn, and act. Augmented reality systems impact what captures users' attention and they alter how AR users direct their attention. Furthermore, the more AR users interact with AR systems, the more they will adjust their information behaviors. They will develop new learning styles to leverage the capabilities of these systems. Likewise, through programmed feedback mechanisms, AR systems themselves will learn and adapt to their users' idiosyncratic information behaviors. Moreover, the habitual use of AR systems will likely impact AR users' decision-making because

it will offer instantaneous access to expertise and an expanded range of knowledge from which to reference. The use of AR systems will change how AR users encode, interpret, and interact with their world.

Given that AR systems appear to be on the cusp of large-scale commercial adoption it is important that the military consider the likely ramifications this technology will have. The following paper argues that AR systems will serve as the next revolution in information technologies and as such it should be leveraged by the U.S. military to maintain its relative information superiority advantages. The use of AR systems at the tactical level and operational level would provide each branch of service marked improvements in a variety of tasks. Furthermore, the use of AR systems by operational leaders and their staffs would provide expanded abilities to understand complex operating environments and new means to command and control tactical forces.

If the military determines to integrate AR systems into its daily garrison activities, and onto its combat battlefields, it will have to overcome a number of challenges and mitigate certain risks. The greatest limiting factor to introducing such a disruptive technology as AR will be overcoming policy restrictions particularly as they relate to privacy, security, and data-classification. However, other difficulties will exist from overcoming anti-technology biases to allaying fears of increased micromanagement due to pervasive presence of communication systems. In the end, however, each of these challenges comes with an opportunity for increased combat effectiveness.

The time has come for the military to begin planning for a future with AR systems. It can best prepare by anticipating future back-end infrastructure requirements and developing battle management systems that readily share information due to prescribed interoperability and

standardization requirements. Likewise, the military should refine its overall information management plan to ensure AR systems can maximize their ability to access and contribute to it. Furthermore, the military should define its unique requirements for AR systems now to ensure they have access to future commercial offerings that are both intuitively controlled and designed for tactical use. Finally, the military must consider developing new organizational structures, policies, and doctrine to prepare for the inevitable changes AR systems will inspire.

Introduction

U.S. military supremacy depends on the relative technological superiority of its combat systems. As technologies advance, the U.S. seeks to retain its military advantage by integrating new inventions that will make its forces more lethal and better able to survive in combat. It makes these investments so as to maintain its relative advantage in combat effectiveness over other militaries. Even though basic materials have improved and mechanical engineering has modernized over the past fifty-years, the one particular technology that has transformed the U.S. military more than any other is information technology (IT).

Since the advent of the micro-chip, the rate of improvement in IT has far surpassed advances in other technologies. IT advances at an exponential rate.[1] Gordon Moore noted early in the start of the micro-chip revolution, IT components appeared to double their capacity nearly every 12-18 months (i.e. processing speed, memory, etc.). At the same time, the cost of these components decreases with time. Recognizing this, the U.S. military has viewed advancements in IT as a driving force for change and improvement in its combat systems. From early investments in battlefield management systems to the development of modern precision-guided munitions, the U.S. military has sought to leverage emerging IT systems and technologies to improve its forces across all echelons.

The central way that IT systems increase the combat effectiveness of military forces is by providing for and applying information superiority. Information superiority is the ability to collect, process, and share information more effectively than an adversary.[2] The U.S. military has determined that it is absolutely essential to maintain information superiority over adversaries.

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[1] Ray Kurzweill, "The Law of Accelerating Returns," (Kurzweil Accelerating Intelligence, March 7, 2001, http://www.kurzweilai.net/the-law-of-accelerating-returns, accessed October 8, 2015.

[2] David S. Alberts, "Key Concepts for Information Superiority," (Military Technology, Vol 11., 2008), p. 75.

The U.S. military regularly delivers precision-strike munitions with long stand-off ranges, employs network-centric forces, and conducts effects-based operations in order to achieve U.S. objectives.[3] The command and control (C2) challenges in coordinating these types of operations require robust IT systems. As such, the U.S. military continues to seek out new IT systems capable of improving its performance.

One emerging IT tool that promises to increase the combat effectiveness of U.S. forces is augmented reality (AR). Augmented reality systems are an information technology used to enhance real-world experiences. Unlike virtual reality systems that immerse users in completely computer generated experience, AR provides virtual content over AR users' perceptual field-of-view (FOV). They create an interactive experience between AR users, their environments, and virtual content.

Leading commercial IT companies and the defense industry recognize the potential of AR and have invested heavily in developing commercial AR hardware and operating systems. Products such as Google Glass, Sony's SmartEyeglasses, and Microsoft's HoloLens have emerged as commercially viable AR devices.[4] Other AR display devices developed by Epson, Inforod, Vuzix, Mirama, and MetaPro are demonstrating the potential of augmented reality.[5] In the defense sector, BAE Systems, Rockwell Collins, and Lockheed Martin have engineered AR capable devices mostly for pilots and vehicle operators. As these and other AR devices make their way into commercial markets AR software engineers see the value in investing in the development of AR applications. They are accelerating their investment in AR app development

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[3] Ibid.

[4] Jessi Hempel, "Project Hololens: Our Exclusive Hand-on with Microsoft's Holographic Goggles," (*Wired*, January 15, 2015).

[5] Anand Dibble, *12 Promising Augmented Reality Devices – The State of AR Hardware*, (Brainberry Global, September 16, 2014, http://brainberryglobal.com/12-promising-augmented-reality-devices-state-ar-hardware/, accessed August 20, 2015).

due to the anticipation of large-scale consumer adoption of AR systems.[6] Furthermore, annual revenue from the sale of AR applications continues to grow and is expected to increase from $247 million in 2014 to over $2.4 billion in 2015.[7] In fact, some analysts believe that virtual and augmented reality technologies will be worth as much as $150 billion as early as 2020.[8]

A large reason the AR commercial sector has reached a tipping point for large-scale consumer adoption is due to the maturation of the component technologies incorporated into AR systems. The director of Intel Labs recently noted that the computer technologies, communications technologies, and sensor technologies have all matured to a point where the potential for high-volume consumer wearable AR devices is practicable.[9] The proliferation of digital sensors and the increase in their capabilities enabled AR systems with new means to encode the world. In addition, the expansion of high-speed mobile internet enables AR systems to access external data sources and computational resources it requires. In addition, the emergence of super-computational processing that can render high-definition 2D and 3D information in real-time enables the high-quality AR interactive experience consumers have come to expect.

The convergence of viable AR devices, a robust community of AR software developers, a growing demand signal from consumers, and the emergence of the back-end IT infrastructure AR requires, has convinced many commercial analysts that AR will soon enter a period of rapid

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[6] ABI, *Cloud Strategies for Augmented Reality,* (ABI, July 3, 2013, https://www.abiresearch.com/press/developers-to-invest-25-billion-in-augmented-reali/, accessed August 20, 2015).

[7] Juniper Research, *Mobile Augmented Reality: Smartphones, Tablets and Smart Glasses 2013-2018,* (Juniper Research, http://www.juniperresearch.com/researchstore/enabling-technologies/augmented-reality/consumer-enterprise-vehicles, 2013).

[8] Digi-Capital Report, "Augmented/Virtual Reality Report Q2" (Digi-Capital, April 2015, http://www.digi-capital.com/news/2015/04/augmentedvirtual-reality-to-hit-150-billion-disrupting-mobile-by-2020/#.ViwTSsuFNjs, accessed September 12, 2015).

[9] Larry Greenemeier, "The Future of Smart Glasses," (Scientific American, Vol. 309, July, 2013).

growth. AR has reached a tipping point and many believe AR will prove to be a "platform integral to the consumer's ecosystem and daily life".[10]

The likely symbiotic relationship between humankind and AR systems has the potential to fundamentally change how people interact with each other and their environments. As such, the time has come for organizations to consider the benefits and challenges their personnel will experience once AR systems are fully adopted. This paper will explain these benefits and challenges as they relate to the use of AR systems by the U.S. military. It will also explain the specific cognitive factors affected by AR systems and what this means for human attention, learning, and decision-making. Furthermore, this paper will explain how the integration of AR systems will improve decision-making at the tactical and operational levels – and thereby increase the overall combat effectiveness of U.S. forces. Finally, it will offer recommendations for how the U.S. military can best prepare for a future world with AR systems.

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[10] Juniper Research, 2013.

Background: Information Superiority and Combat Effectiveness

Those organizations that adapt and exploit advances in information technology tools gain a competitive advantage over those that fail to do so.[11] Information technology systems enable organizations to achieve information superiority so as to make more effective and efficient decisions.[12] The U.S. military recognizes this and continues to develop, procure, and integrate systems it believes will benefit its tactical combat units and operational leaders. Ultimately, as the capabilities of information systems increase, they enable military forces at both the operational and tactical levels to better orient and direct forces toward emerging threats.[13]

The U.S. military has a long history of researching and developing new IT systems to help it achieve information superiority. As new innovations emerge it continues to seek ways to leverage their capabilities so as to maintain its information superiority advantage.[14] It does this because military leaders need both access to timely and accurate information about their operating environment and the means to communicate their vision to decision-makers and their forces.[15] During combat, information superiority – i.e., the ability to provide vital information to forces with "superior timeliness, relevance, accuracy, and comprehensiveness" than an adversary

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[11] David S. Alberts, and Richard E. Hayes, *Understanding Command and Control (*Washington, D.C.: DoD Command and Control Research Program, 2006).
[12] Ibid.
[13] JCS, JF-2020, 2012.
[14] Walter Perry, David Signori, and John Boon, *Exploring Information Superiority: A Methodology for Measuring the Quality of Information and Its Impact on Shared Awareness*, (Rand Corporation report for U.S. SECDEF, 2004).
[15] JCS, *Capstone Concept for Joint Operations: Joint Force 2020,* (Washington, D.C.: Joint Chiefs of Staff, 2012). See also David S. Alberts, *The Agility Advantage, (*Washington, D.C.: DoD Command and Control Research Program, 2011).

can achieve - can be decisive in determining the outcome.[16] Now, more than ever information superiority is a prerequisite for mission success.[17]

At the tactical level, information superiority can determine survival or peril. In combat, information superiority enables military forces to locate and target enemy forces faster than they can do the same.[18] Speed in decision-making allows one to disrupt an adversary's ability to respond and react and helps tactical units gain and maintain the *tactical imperative*. At the tactical level, information superiority also helps combat forces understand the location and disposition of friendly forces. This increases their overall unity-of-effort and prevents inadvertent accidents and fratricides. Information superiority, in addition to aid combat forces defeat an adversary, and support friendly forces, can also help to prevent collateral damage and civilian casualties. Beyond the immediate life-and-death benefits at the tactical level of information superiority – it can increase combat effectiveness at a much broader scale operationally.

At the operational level of war, information superiority enables the C2 efforts of Joint-Task-Force operational commands. It allows operational commands the ability quickly assemble a full range of joint weapon systems in order to apply the maximum potential of the combat power available at a given space in time. Data from the operational environment is considered along with information about friendly and adversarial forces to provide a body of knowledge from which operational commands can base their decisions.

To achieve information superiority, the U.S. military operates in accordance with the principles of Network Centric Warfare (NCW). NCW emphasizes decentralized battlespace

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[16] Mark Jansen, Hugo Trépant, Abdulkader Lamaa, and Andrew Suddards, *Achieving information superiority: Five imperatives for military transformation*, (Booz and Company report, 2014).
[17] Col William Hartig, Thinking about Complexity, (Newport, RI: USNWC, 2012). See also David S. Alberts and Richard E. Hayes, Power to the Edge: Command, Control, in the Information Age, (Washington, D.C.: DoD Command and Control Research Program, 2005).
[18] Marine Corps Doctrinal Publication (MCDP) 1-3, *Tactics*, (Department of the Navy, Washington, D.C., 1997).

information collection, analysis, and dissemination to and from the forward edges of combat.[19]

Network Centric Warfare focuses on sharing situational awareness amongst military forces in a

collaborative manner. This collaboration is intended to synchronize distributed efforts such that

dispersed combat power can be focused at the decisive point in a conflict. The principle

challenge of maintaining accurate situational awareness (SA) in a common operating picture has

been largely delivered in modern battle management systems. The problem is that much of this

battlespace SA remains locked within computers and tethered within tactical operating centers.

The next step in enhancing the SA provided within NCW will come in the migration of this

information to smartphones and wearable technologies.

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[19] David S. Alberts, John J Garstka, and Frederick P Stein, *Network Centric Warfare: Developing and Leveraging Information Superiority (*Washington, D.C.: DoD C4ISR Cooperative Research Program, 1999).

Augmented Reality Technology Review - Smartphones, HUDs, and HMDs

The following sub-sections will provide descriptions of various forms of AR technologies. Though the true beginning of AR began with the development of heads-up-displays (HUD) the recent explosion in commercial AR applications has stemmed from their use in smartphones and mobile devices. As such, this section will begin by describing this trend and explaining what it portends for future AR system development.

Smartphones

The first commercially viable AR devices were smartphones. In 2007, roughly 20% of global customers had a smartphone. Today in 2015, over 80% of first world nations do with other countries close behind.[20] Smartphones allow users to unplug from their offices and homes and effortlessly begin to merge digital content with real-life experiences. A smartphone provides its users a variety of capabilities. The most obvious use for smartphones concerns the ubiquitous access to communication, whether it is voice, video, or chat. However, it is the access to the limitless catalogue of digitized knowledge and information processing that has had such a transformative impact and kick-started the development of AR applications. Smartphones, like computers before them, offer an externalized means of cognition. However, unlike computers, smartphones enable their users to interact with this content everywhere they have access to a wireless signal. Augmented reality applications leverage this access to content and external processing to deliver digital data meant to enhance one's understanding of, and interaction with the real-world.

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[20] Gartner historical, Jefferies and Company, Inc. "Exhibit 1: Smartphone Penetration Estimates," (http://zeendo.com/info/smartphone-users-by-country/, accessed October 11, 2015).

Smartphones have transformed how people interact with their environments in a number of ways. First, they have made it easier to navigate to desired locations. Smartphones have GPS sensors that track their location and navigation applications that help users plan routes based on this information. Today smartphone users always know how to get to their desired location. Next, smartphones allow users to quickly query online content to answer questions and fill in gaps in their understanding. Whether it's a date in history or the name of a forgotten actor, smartphone users can quickly find answers through an online search, thereby expanding their understanding. In addition, smartphones provide access to decision-making aids. For example, when determining whether a product sold in a store is a fair price, many shoppers will frequently use their smartphones to compare prices. Furthermore, many consumers use their smartphones to research reviews and ratings for products and services. Many shoppers will quickly look up a product's rating by other consumers before they decide to make a purchase. They will also examine ratings about the quality of experiences – such as dining at a restaurant, the quality of entertainment, or the condition of a hotel and its services. By providing navigational tools, enriched understanding, and expert advice, today's smartphones have already begun to augment their users' sense of reality.

Smartphones also placed a multitude of digital sensors in the hands, and on the bodies, of their users, thereby augmented their sensory-perceptual awareness. Through contextually aware applications, the data from these sensors provides environmental feedback to their users. This sensory-perceptual expansion has generated novel means to enhance the understanding of users' environments and themselves. For example, biofeedback applications can sense a user's temperature, and heartrate, and motion-state in order to estimate changes in activity levels and the corresponding caloric use. These sensors are also being employed in the workplace.

Engineers are increasingly turning to their smartphones to test products and equipment through applications that use the sensors native to these devices to create tachometers, hygrometers, seismographs, frequency analyzers and other instruments.[21]

The sensor data from individual smartphones is also being combined with the data from other mobile devices and external data sources to provide a larger-scale of shared awareness known as crowd-sensing.[22] For example, the relative speed of a collection of smartphones traveling in cars on the same stretch of road can be collated to measure traffic patterns. Likewise, companies like Open Signal, entice users to participate in their crowd-sensing enterprise by allowing them to use their application to find where the best free-Wi-Fi signals reside while their devices begin to collect and share Wi-Fi sensor data from their device back to Open Signal's user base.[23] Crowd-sensing and crowd-sourcing smartphone applications have also been developed for other spatio-temporal analytical forecasts. Weather forecast applications can combine sensor data from dispersed smartphones to provide more accurate measurements of changing meteorological conditions. Similarly, government health services can monitor the mobility behavior pattern of individuals traveling two and from clinics and hospitals to predict potential disease outbreaks or other emergencies.[24] The measured convergence of smartphones can indicate flocking or queuing.

When combined with details about smartphone users' internet search history, communication patterns, or social network connections, this data can become invaluable in

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[21] Kathryn Alexander, "Instruments: Sensors and Apps are Turning Smartphones into Engineering Measurement Tools," (Mechanical Engineering, September 1, 2015).

[22] Moo-Ryong Ra, Bin Liu, Tom La Porta, Ramesh Govindan, "Medusa: A Programming Framework for Crowd-Sensing Applications," Mobisys' 12, Low Wood Bay, Lake District, UK, June 25-29, 2012)

[23] Paul Sawers, "How OpenSignal uses Millions of Smartphones to Create a Giant Social Library," (VentureBeat, January 30, 2015, http://venturebeat.com/2015/01/30/how-opensignal-uses-millions-of-smartphones-to-create-a-giant-social-laboratory/, accessed August 12, 2015).

[24] Paul Lukowicz, Alex Pentland, and Alois Ferscha, "From Context Awareness to Socially Aware Computing," (Pervasive Computing, IEEE CS, Jan-Mar, 2012), p. 37.

understanding and predicting behavior. Corporations and governments desire to have this information – one for profit the other for security. This raises a number of civil liberties concerns. Despite various security and privacy regulations in place to limit exactly what an organization can obtain from users' smartphone sensor-data – many users unwittingly allow for this information to be exchanged when they enable location-services to operate.[25] Time will tell whether most are willing to forgo these concerns for the benefits they receive by participating in crowd-sourcing applications. It appears that the trend is moving away from individual privacy toward shared-awareness.

In addition to the AR innovations of improved sensory-perceptual experiences of the self and collective, the next advancements in enhancing real-world experiences comes in the form of automated personal assistants. These personal assistants are now available in all major smartphone operations systems. Programs like Apple's Siri, Google's Now, and Microsoft's Cortina respond to user's directions and questions, much like one would expect a human secretary or personal assistant would. These semi-artificially intelligent applications are accelerating the human-AR symbiotic relationship. No longer do people have to depend only on their experience and understanding of how to interact with this brave new digital world – they can ask a digital companion for help. These assistants are beginning to learn their users' behaviors and predict what they will need and when they need it.[26] They are also beginning to direct the behavior of their users rather than waiting to be directed. Through assigned reminders, context-awareness, and object recognition, automated assistants can alert their users. These prompts may help the forgetful or distracted, but they also can become an auto-pilot feature for

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[25] Rahel Gebreyes, "Research Shows Location Tracking Apps Like Grinder Could Threaten Your Privacy," (Huff Post, January 28, 2015, http://www.huffingtonpost.com/2015/01/28/location-tracking-grindr-privacy_n_6564864.html, accessed October 24, 2015).
[26] Alex Fitzpatrick, "Why We Finally Have the First True 'Smartphones'," (Time.com, June 12, 2015).

personal every-day routines. Smartphone users access to these types of virtual personal assistants is clearly augmented their real-life experiences and behaviors.

Access to these AR capabilities, along with the myriad of other benefits of smartphones has made them an indispensable part of everyday life for many. In fact, some would rather leave home today without their wallets, then without their smartphones.[27] The proliferation of smartphones, with their various AR applications, has demonstrated the potential of AR systems to enhance experiences and improve users' interactions with their environments. The user experience of AR applications with smartphones, however, leaves much to be desired. As a result, AR devices are being designed to provide uninterrupted AR experience for users. Unlike smartphones that move from pockets to hands to eyes - they are worn as glasses, visors, or contact lenses. As such, they provide continuous access to AR content. With their arrival, AR systems will fundamentally change how users interact with each other and their surroundings – just as smartphones have done over the past decade.

Heads-Up-Displays (HUD)

Heads-Up-Displays (HUD) were the first AR systems developed to present digital data within a user's field-of-view (FOV).[28] Field-of-view AR devices, like a HUD, provide a mediated form of reality by overlaying computer generated information on users' visual perceptual experience. Augmented reality systems achieve this by combining the virtual with the real. It registers and processes sensor data from a user's environment so it can produce and

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[27] Meena H. Duerson, "We're Addicted to Our Phones: 84% Worldwide Say They Couldn't Go a Single Day Without Their Mobile Device in Their Hand*,"* (August 16. Accessed May 15, 2015. http://www.nydailynews.com/life-style/addicted-phones-84-worldwide-couldn-single-day-mobile-device-hand-article-1.1137811, 2012).

[28] Mark A. Livingston, Lawrence J. Rosenblum, Dennis G. Brown, Gregory S. Schmidt, Simon J. Julier, Yohan Baillot, J. Edward Swan II, Zhuming Ai, and Paul Maassel, "Military Applications of Augmented Reality," (Naval Research Laboratory, Washington, D.C., 2011).

anchor computer generated information relevant for a given setting. It merges digital content with users' perceptual experience by rendering 2D and 3D graphics over their visual FOV as they move through and interact with their surroundings. This experience differs from Virtual Reality (VR) which generates fully immersive virtual environments in which users interact with virtual content. Augmented reality systems, on the other hand, are designed for use in the real-world. The earliest forms of FOV AR systems were developed for fighter pilots in the form of Heads-Up-Displays (HUD).[29]

The military has continued to invest in the development of HUDs because it was found that pilots who used HUDs operated their aircraft more ably than when they relied on conventional flight instruments alone.[30] A HUD in an aircraft employs a semi-transparent combiner located between the pilot's eyes and the aircraft windshield. AR information is projected onto the combiner enabling the pilot to view both the digital content and the real-world scene. The first commercially available HUDs were designed to help civilian pilots during landings.[31] Today's aircraft HUDs, however, include information about airspeed, altitude, elevation, flight path, navigation, as well as automatic flight control system information.[32] Aircraft are not the only vehicles to employ AR HUD capabilities.

Augmented reality HUDs have also been developed for watercraft and the maritime environment. The use of these systems provided increased situational awareness and improved precision piloting.[33] The Office of Naval Research supported the development of the Augmented Reality for the Common Operational Picture (ARVCOP) system. This AR system tracks the

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[29] Gregory Kipper and Joseph Rampolla, *Augmented Reality: An Emerging Technologies Guide to AR.* (Waltham, MA: Elsevier, 2013).
[30] Robert B. Wood & Peter J. Howells, "Head-Up Displays," (*The Avionics Handbook*, CRS Press, LLC, 2001).
[31] Ibid.
[32] Ibid.
[33] Thomas Zysk, Jeffory Luce, and James Cunningham, "Augmented Reality for Precision Navigation: Enhancing Performance in High-Stress Operations," (GPSWorld.com, June 1, 2012, http://gpsworld.com/defensenavigationaugmented-reality-precision-navigation-13032/), pp. 47-51.

precise location of a vessel and then projects geographically registered navigation overlays for pilots to see as they navigate a pre-planned route. During evaluations, the use of this system helped reduce errors from translating 2D map data to the pilot's 3D perspective.[34] When maritime pilots used the ARVCOP to perform precision piloting tasks they navigated more precise routes along planned routes. Operators using ARVCOP also reported they were more confident in maneuvering in unfamiliar waters, at higher rates of speed, as well as at night or in inclement weather.[35] These benefits have also found their way from the water to the road.

Automotive manufacturers such as BMW, Mercedes-Benz, Mitsubishi, and SAAB have recently made investments in developing HUD like windshields. These innovations aim to keep driver's attention focused on the road ahead by displaying traditionally dash-mounted information in their FOV.[36] This information includes navigation route guidance, vehicle-to-vehicle safety alerts (i.e. warnings about proximity to other vehicles), as well as signals for lane departures and traffic alerts.[37] It may soon include AR aids for driving during zero-visibility conditions (i.e. when fog, rain, or snow occludes vital visual navigational information). An onboard computer will use the car's laser and radar sensors, and cross reference available 3D maps of an area, to project AR driving cues on the car's windshield.[38] This AR information provides indispensable information to drivers without requiring them to look away from the environment.

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[34] Ibid, p. 49.

[35] Ibid, p. 48.

[36] Nick Jaynes, "Forget head-up displays. Mitsubishi's concept has an augmented reality windshield," (Mashable, October 9, 2015, http://mashable.com/2015/10/09/mitsubishi-ex-concept/#CA_HwUPo5uqu, accessed October 11, 2015.)

[37] Ibid.

[38] Alex Oagana, "Three Future Safety Technologies That Could Change Driving as we Know it," (Autoevolution, October 7, 2015, http://autoevolution.com/news/three-future-safety-technologies-that-could-change-driving-as-we-know-it-100779.html, accessed October 11, 2015).

The military has also researched AR HUD capabilities for ground vehicles. Like aircraft and commercial vehicles, military vehicle crews can also benefit from the navigational aids and enhanced situational awareness provided by AR systems integrated with a vehicle's sensors. However, increased calls for the use of AR systems has resulted from the increasing dangers to exposed vehicle crew members and the growth of remotely controlled weapon systems.[39] One vehicle AR HUD system available for military use was developed by SAAB. This AR system employs components that include a Local Situational Awareness System (LSAS), Driver Vision Enhancement System (DVES), and a Vehicle Camera System (VCS) to provide high-resolution images, and sensor data, with low latency to drivers and their crew.[40] These vehicular components can provide 360 degree of the vehicle's exterior, IR cameras for when climate conditions occlude optical cameras, and the connection and control of weapons and their sights.[41] They are also intended to link to other battlefield management systems so that commanders can understand the location and disposition of their forces.[42] These systems are useful, but they still require operators to remain in relatively fixed positions so they can view mounted HUD systems.

Head-Mounted-Displays (HMD)

As the name implies, Head-Mounted-Displays (HMD) are AR systems that a person wears on his or her head. They include helmets with visors, various glasses, as well as contact lenses. These display devices liberate users from HUDs by allowing them the freedom to move their heads without losing sight of AR content. They also allow operators to move from beyond cockpits out into the real-world. They can do this because they precisely track the orientation and

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[39] Brian Kindamo, "Vehicle Situational Awareness," (MilTech, Vol. 1, 2015), p. 48-49.
[40] Ibid, p. 49.
[41] Saab, "Rugged Vetronics Systems," (Saab Corporate Brochure, http://saab.com/globalassets/publications-pdfs/support-and-services/military-electronics-solutions/234-0735_rvs_broschure_a4_update_k5_low.pdf, accessed October 11, 2015).
[42] Ibid, p. 5.

location of the user's head and body and synchronize this information with virtual information rendered to a user's visual FOV.

Head-Mounted-Displays can be categorized in a number of manners – but a common distinction concerns the manner in which information may be visually presented.[43] Three basic categories of HMDs exist. *Monocular* HMDs display information to a single eye. *Biocular* HMDs display information to both eyes, however, this information comes from a single sensor and therefore does not necessarily provide depth cues or perspective. *Binocular* HMDs, however, present two visual images, one for each eye but from sensors that provide 3D perspective.[44] Beyond these three categories the manner in which information is displayed can also differ. Traditionally, HMD had AR information relayed optically and then overlaid on reflective and refractive lens elements.[45] Another feature of many HMDs is their ability to track eye-movements so as to identify the object of a user's attention and to project AR information accurately and in the correction orientation with respect to a user's visual perspective.[46] HMDs can render virtual information in a number of ways. For instance, one HMD technology can use lasers to project an image directly onto the retina of a user's eyes.[47] Another design, developed by BAE Systems employs holographic optics presented between two optic plates to merge real-world information with virtual content.[48] As digital technologies increase in capacity, and decrease in size, they will continue to enable light-weight, high-resolution, high-speed HMDs.

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[43] Michael M. Bayer, Clarence E. Rash, James H. Brindle, "Introduction to Helmet-Mounted Displays," (in. *Helmet-Mounted Displays: Sensation, Perception and Cognition Issues,* Ed. Clarence E. Rash, Michael B. Russon, Tomasz R. Letwoski, Elmar T. Schmeisser, U.S. Army Aeromedical Research Laboratory, Ft. Rucker, AL, 2009), pp. 47-107.
[44] Ibid, p. 49.
[45] Ibid, p. 50.
[46] Jannick Rolland & Hong Hua, "Head-Mounted Display Systems," (Encyclopedia of Optical Engineering, Taylor & Francis, 2005).
[47] Michael M. Bayer, et al., "Introduction to Helmet-Mounted Displays,", p. 52.
[48] Ibid, p. 53.

Original HMDs were developed for military aircraft pilots, due in large part to the same set of motivations that led to the development of cockpit HUDs. The military aviation community began to research and develop HMD systems in the 1970s for both rotary and fixed-wing aircraft. The wide field-of-regard provided by HMDs allows pilots and crews to observe far more of their external surroundings while still receiving system information through the HMD. Beyond this fear, and the navigation capabilities typical of earlier HUDs, most modern aviation HMDs also included weapon sighting information. Access to this information produced a significant reduction in the time required to employ weapons against a target.[49] Furthermore, with the addition of advanced sensors in these aircraft, such as infrared and thermal optics, pilots using HMDs are able to see AR data merged with these enhancing images. All of this additional information increases the ability of pilots and their crews to remain oriented to their surroundings, and employing their weapon systems, while continuing to pilot their aircraft. This allows pilots and crews to maintain SA and allows them to more rapidly orient toward, and remain fixated on adversaries.

The Generation 3 Helmet-Mounted Display System (HMDS) for the F-35 Joint Strike Fighter (JSF) represents that latest assembly of AR HMD technologies. The JSF helmet was designed to produce a symbiotic type relationship between the pilot and the aircraft itself.[50] One of the unique AR capabilities of the JSF helmet is that it allows pilots to see through the aircraft. When they look down, they see the world below. When they look back, they see the horizon behind them. Six cameras are embedded in the skin of the F-35 capturing and relaying their imagery to the pilot's helmet. The visor in the helmet acts like an HMD that presents traditional

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[49] Ibid, p. 56.

[50] Christian Davenport, "Meet the Most Fascinating Part of the F-35: The $400,000 Helmet," (The Washington Post, April 1, 2015, https://www.washingtonpost.com/news/checkpoint/wp/2015/04/01/meet-the-most-fascinating-part-of-the-f-35-the-400000-helmet/, accessed October 11, 2015.

navigational information, along with other battle management system data. F-35 pilots can track the location of friendly and adversarial forces in their helmet's display. Despite its costs, and delays in production due to technical challenges, this new helmet stands as the most advanced AR HMD ever produced.

Modern HMDs have also been developed for military land vehicles. As previously noted, maintaining situational awareness from within an armored vehicle or tank can be a challenge. In a desire to allow the operators and crews of military land vehicles greater situational awareness and freedom of movement within their vehicles BAE has developed an HMD AR system for armored vehicles and tanks.[51] BAE Systems' BattleView 360 system builds upon the efforts it made in developing a backup F-35 HMDS when it appeared that the primary contractor, Rockwell Collins, may not be able to deliver a viable device.[52] BAE Systems' *BattleView 360* provides a common operating picture by presenting and tracking the positions of surrounding features of interest in 2D and 3D modalities.[53] This system inputs data from various optical and infrared sensors on the vehicle and merges this information with digital map data. Operators then use HMD interfaces and touchscreen units within vehicles to visualize this information.[54] The employment of AR HMD systems within military vehicles has demonstrated the exciting potential of these technologies to increase the SA of their crews and the overall effectiveness of these combat systems.

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[51] Anthony Wood, "BAE Systems' BattleView 360 is Made to Raise Situational Awareness in Tank Crews," (Gizmag, September 22, 2015, http://www.gizmag.com/bae-systems-battleview-360/39513/, accessed October 11, 2015).

[52] Lara Seligman, "Rockwell Delivers First Gen 3 Helmet for F-35," (Defense News, August 12, 2015, http://www.defensenews.com/story/defense/air-space/strike/2015/08/12/rockwell-delivers-first-gen-3-helmet-f-35/31538101/, accessed October 11, 2015).

[53] Ola Thoren, "BattleView 360 'See-through' Armored Vehicle System Makes DSEI Debut," (BAE Systems Public Affairs, September 18, 2015, http://www.baesystems.com/cs/Satellite?c=BAENews_Release_C&childpagename=US%2FBAELayout&cid=1434566341731&pagename=USWrapper, accessed October 11, 2015).

[54] Anthony Wood, "BAE Systems' BattleView 360 is Made to Raise Situational Awareness in Tank Crews," (GizMag, September 22, 2015, http://www.gizmag.com/bae-systems-battleview-360/39513/, accessed October 11, 2015).

The success of HMDs used within modern military vehicles has increased calls for dismounted AR HMD systems. In 2009, DARPA began a project called ULTRA-VIS (Urban Leader Tactical Response, Awareness & Visualization), in collaboration with Lockheed Martin and Microvision to develop an HMD for ground forces.[55] This effort sought to provide AR overlays within a tactical optic dismounted personnel could wear on their helmets. The AR software behind ULTRA-VIS, ARA's ARC 4, provides semi-transparent graphical overlays depicting blue forces, hazards, imagery, navigation routes, and alerts.[56] It accepts inputs from a sensor module of cameras, as well as GPS data, head-tracking data, and then fuses this information to render digital content in concert with a user's location and their FOV perspective.[57] The biggest challenge the ARC 4 software had to overcome was tracking a user's precise location as well as their eye movements as they moved. This data enables the ARC 4 software to render digital content over a users' real-world view and maintain its location and correction orientation.[58] In 2014, DARPA ended its ULTRA-VIS program, however ARA has continued to develop its ARC 4 software, and others have continued to develop AR HMDs.

BAE System's Q-Warrior display, which had also been developed as part of the ULTRA-VIS program, has shown the most promise for military dismounts. The Q-Warrior display, is a light-weight, helmet-mounted, monocular AR optical device.[59] It attaches to a helmet's FAST

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[55] Alexis C. Madrigal, "How DARPA's Augmented Reality Software Works," (The Atlantic, May 27, 2014, http://www.theatlantic.com/technology/archive/2014/05/hows-darpas-augmented-reality-software-works/371652/, accessed October 17, 2015).

[56] Joey Cheng, "DARPA-funded Augmented Reality Technology Moves to Commercial Sector," (Defense Systems, May 29, 2014, https://defensesystems.com/articles/2014/05/29/ara-augmented-reality.aspx, accessed October 16, 2015).

[57] Rose Evelth, "Augmented Reality System Goes from Military to Market," (The Daily Beast, May 27, 2014, http://www.thedailybeast.com/articles/2014/05/27/augmented-reality-system-goes-from-military-to-market.html, accessed October 16, 2015).

[58] Alexis C. Madrigal, "How DARPA's Augmented Reality Software Works," 2014.

[59] Allen McDufee, "At Last, A Google Glass for the Battlefield," (Wired, February 24, 2014, http://www.wired.com/2014/02/battlefield-glass/, accessed October 17, 2015).

rail system and weighs about 400 grams.[60] The device provides a high-resolution transparent

display on which full-color, 3D graphics are shown. Though ARA's ARC 4 AR software has

served as the brains within the Q-Warrior display, other AR software could be developed to

control Q-Warrior. Likewise, ARA's ARC 4 AR software has been integrated with different

wearable displays besides BAE Systems Q-Warrior, for example: Lumus, Vusix, and Exelis.

Currently, despite a number of efforts to field an AR HMD system within each branch of service,

no single software – display device solution exists outright. Many are in development, but the

field of candidate AR HMD systems remains broad.

Augmented Reality Visors, Glasses, and Contact Lenses

Augmented reality glasses and AR contact lenses are another form of an AR HMD – they

just happen to be less bulky and cumbersome. These systems seek to scale-down the size and

complexity of AR systems from that found in AR HMDs so that users can wear these devices

and interact with them intuitively during their daily lives, at home, in the office, and everywhere

in between. The sea-change in AR, and the reason why so many potential AR users, and analysts,

are excited about the future of AR technologies, is because of the commercially viable AR smart-

glasses currently coming to market. The following section will briefly outline the currently

available AR smart-glasses and AR contact lenses.

<u>Microsoft – HoloLens</u>. Microsoft has dedicated over a thousand employees and a billion dollars

toward the development of its AR product – HoloLens.[61] HoloLens is a lightweight head-

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[60] BAE Systems Q-Warrior Data Sheet,
http://www.baesystems.com/cs/Satellite?blobcol=urldata&blobkey=id&blobtable=MungoBlobs&blobwhere=14346 45945575&ssbinary=true, accessed October 17, 2015.
[61] Bruce Harris, (Microsoft HoloLens technology evangelist, interview, September 18, 2015).

mounted AR visor that displays HD holographic images binocularly.[62] It uses both optical cameras and infrared sensors, originally developed for the Microsoft Kinect, to register a user's surroundings. It has an internal holographic processing unit that combines this sensor data, with AR application data, to geo-register and display holographic digital content.[63] It has no dangling cords or wires. It is currently meant for indoor use. It will run Microsoft's native operating system Windows 10. For this reason, any Windows 10 compatible software should be able to work within HoloLens. Content from these applications can be geo-registered and anchored to real-world locations in 2D and 3D. It also has a large number of AR applications specifically developed by Microsoft for use in HoloLens.[64] Microsoft has said that one of its primary focuses for HoloLens use would be for enterprise users.[65] In particular, organizations that design and produce real life objects – i.e. graphic designers, engineers, and architects – could find HoloLens's ability to help them visualize their creations in 3D, to scale, real-world virtual representations incredibly useful.

Sony – SmartEyeglass. Sony has developed a set of AR glasses in SmartEyeglass that provide digital content but do not deliver an AR experience. This system has an optical camera, microphone, noise suppression sub-microphone, Bluetooth capability, Wi-Fi capability, compass, gyroscope, accelerometer, and brightness sensor.[66] It displays digital information from a tethered Bluetooth or Wi-Fi Android phone, binocularly in monochrome – green.[67]

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[62] Microsoft, "HoloLens Hardware," (http://www.microsoft.com/microsoft-hololens/en-us/hardware, accessed October 17, 2015).

[63] David Murphy, "Augmented Reality Glasses: What You Can Buy Now (or Soon)," (Tom's Guide, October 6, 2015, http://www.tomsguide.com/us/best-ar-glasses,review-2804.html, accessed October 17, 2015).

[64] Ibid.

[65] Max Slater-Robins, "Here's Everything We Know About Microsoft's Augmented Reality Headset – HoloLens," (Business Insider, October 17, 2015, http://www.businessinsider.com/microsoft-hololens-augmented-reality-headset-roundup-2015-10?r=UK&IR=T, accessed October 18, 2015).

[66] Sony, "SmartEyeglass," (https://developer.sony.com/devices/mobile-accessories/smarteyeglass/, accessed October 18, 2015).

[67] Ibid.

SmartEyeglass provides information such as directions, Tweets, and other information related to a user's location. They even include real-time voice translations from input audio that then appears as displayed text. The smart-glasses themselves are meant to be less conspicuous as an AR HMD system, yet they still have a wire that dangles from them to a Sony Eyeglass' control pack, which seems obtrusive to some who have reviewed these devices.[68] This control pack contains the touch controls, battery, microphone, and speaker for the smart-glasses.[69]

Google – Glass. Google Glass was recently discontinued, however Google does not appear complete this this project with Project Aura perhaps serving as a revival of this effort.[70] The original device given to developers offered a tiny mounted display that attached to a pair of standard glasses. It came with an optical camera, Bluetooth capability, Wi-Fi capability, and 12GB usable memory. It relied on a connection to a user's smartphone for many other sensor inputs. Inside its display, a number of superimposed information screens displayed information such as the weather, alerts, missed calls, and turn-based navigation based on a user's smartphone's GPS. Glass could use third-party Android-friendly applications as well.[71] This information was not geo-registered to a user's environment and therefore acted as mediated information and not true AR.

Recon Instruments (an Intel company) - Recon Jet Recon Jet is similar to Google Glass, only sportier. It has an HD camera, infrared sensor, Bluetooth capability, Wi-Fi capability, 8 GBs of usable storage, built-in GPS, gyroscope, accelerometer, altimeter, barometer, magnetometer, and pressure sensor.[72] It uses Intel's dual-core processor and can pair with a

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[68] Rich Trenholm, "Sony's Prototype EyeGlass Smart Specs Eye up Google Glass," (CNET, September 5, 2014, http://www.cnet.com/products/sony-smart-eyeglass/, accessed October 18, 2015.
[69] Sony, 2015.
[70] Antony Maina, "Remember Google Glass? A Revival is Being Planned," (Small Business Trends, September 22, 2015, http://smallbiztrends.com/2015/09/google-glass-project-aura.html, accessed October 17, 2015).
[71] Murphy, "Augmented Reality Glasses: What You Can Buy Now (or Soon)," 2015.
[72] Recon Instruments, "Recon JET," (http://www.reconinstruments.com/products/jet/, accessed October 17, 2015).

user's smartphone to get caller ID, SMS notifications, and social media information.[73] The AR display is mounted to a pair of polarized sports frames; however unlike Google Glass, it is presented in the bottom of the right lens versus the top. Recon Jet is designed for athletic use such as running or biking. It delivers contextually relevant information, but like Google Glass, is does not geo-register and render digital content. It has sports-themed applications capable of tracking metrics such as speed, pace, distance, and heartrate.[74] Though it has a built-in microphone, it cannot yet be controlled through voice commands.[75]

Optivent - Ora-1. Optivent's Ora-1 is similar to other smart-glass form factors, such as Google's Glass and Recon Instrument's Jet. Like these devices, it has a small screen that augments a user's vision. It has an optical camera, 1080p video recording, Bluetooth capability, Wi-Fi capability, 4GB usable memory, ambient light sensor, and a photochromic lenses. The key difference between the Ora-1 and similar devices, is that its small display screen can move. In addition, its photochromic lenses adjust to sunlight. Furthermore, the Ora-1 can serve as a stand-alone Android device capable of running Android applications without the need to pair it with a smartphone.[76]

Vuzix - M100 Smart Glasses. Vuzix has long been a leading developer of AR glasses. Its M100 Smart Glasses comes in two primary categories – one attached to a pair of glasses and another that are built into a pair of safety goggles.[77] It comes with an optical camera, 1080p video, Bluetooth capability, Wi-Fi capability, 4GB usable memory, and built-in GPS. Vuzix has developed its own applications for the M100 Smart Glasses, but Andoid applications can also be

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[73] Ibid.
[74] Ibid.
[75] Murphy, "Augmented Reality Glasses: What You Can Buy Now (or Soon)," 2015.
[76] Murphy, "Augmented Reality Glasses: What You Can Buy Now (or Soon)," 2015.
[77] Vuzix, "Background Information," (Vuzix Product Website, 2014, https://www.vuzix.com/news/background_information/, accessed October 17, 2015).

used.[78] It comes pre-loaded with an audio-recorder, camera, photo gallery app, and eyesight-based bar code scanner. The M100 Smart Glasses can be controlled through voice interactions or by tapping various hardware buttons on the device, or through an Android phone with a virtual mouse and keyboard.[79]

Meta - Meta 1. Meta developed an AR visor similar in size and shape to Microsoft's HoloLens. Like HoloLens, Meta 1 is meant for indoor use. It has an optical camera, a 3D depth camera, integrated 3D Dolby audio, 360-degree head-tracking, 9-axis inertial measurement unit, compass, gyroscope, accelerometer, and HDMI input.[80] This system is designed to fill the FOV of users – thereby engrossing a user's visual experience. Meta 1 can sense and track a user's hand movements, which in turn can allow its users to use their hands to interact with virtual content – grabbing and moving virtual objects and moving and rotating them in space.[81] Meta has also recently announced the development of Meta Pro – a sleeker pair of glasses that appear more like Ray-Ban sunglasses than AR glasses.

Epson - Moverio BT-200 and BT-2000. Epson developed its Moverio BT-200 and BT-2000 for true AR experiences. Both devices have a depth-sensing optical camera, Bluetooth capability, Wi-Fi capability, 8 GB internal memory, removable memory microSDHC card, 3D Dolby audio, compass, gyroscope, and accelerometer.[82] Both systems also rely on a control unit tethered to the display visor. They are binocular with two screens display a 960 x 540-pixel image over each eye of a user.[83] The BT-200 supports gesture recognition and 3D mapping of a

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[78] Ibid.
[79] Murphy, "Augmented Reality Glasses: What You Can Buy Now (or Soon)," 2015.
[80] Meta, "Meta 1 Developer Kit," (https://www.getameta.com/products#, accessed October 17, 2015).
[81] Murphy, "Augmented Reality Glasses: What You Can Buy Now (or Soon)," 2015.
[82] Epson, "Epson Smart Eyewear – Moverio BT-2000 Smart Headseet," (Epson, http://www.epson.com/cgi-bin/Store/jsp/Landing/moverio-bt-2000-smart-headset.do, accessed October 17, 2015).
[83] Epson, "Moverio BT-200 Smart Glasses (Developer Version Only)," (http://www.epson.com/cgi-bin/Store/jsp/Product.do?sku=V11H560020, accessed October 17, 2015).

user's surroundings.[84] These devices are Android compliant. The BT-2000 differs from the BT-200 in that it also has industrial grade IMU sensor and a more ruggedized design. Epson designed the BT-200 for industrial workplaces.[85]

GlassUp. Unlike all of the previous smart-glasses described, GlassUp does not have an optical camera, nor does it have multicolor display capability. Instead, users get digital content displayed only to the center of these glasses.[86] Emails, text messages, social media updates all pop up in the center of a user's view, remain for a few seconds, and then disappear.[87] It has Bluetooth capability, an accelerometer, compass, ambient light sensors, precision altimeter and it is controlled via a touch-pad.[88] GlassUp's developers designed their system to provide simple aids, and not for entertainment, nor semi-immersive virtual experiences.[89]

Google Contact Lenses. Recently, Google filed a patent for a wearable communication device saturated with sensors, memory, a microprocessor, solar-power cells, and shaped like a contact lens.[90] The lens would be powered by the solar-power cells which would harvest energy from the sun and other light signals. The contact lens could relay information it can chemically detect, such as a user's body temperature, blood-alcohol level, exposure to allergens or other airborne materials back to an external device.[91] Google's patent also adds that the lens would be capable of communicating with computers or mobile devices, and could potentially read

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[84] Ibid.
[85] Ibid.
[86] GlassUp, "GlassUp Features," (http://www.glassup.net/features, accessed October 17, 2015).
[87] Ibid.
[88] Ibid.
[89] Ibid.
[90] Mike Murphy, "Forget Google Glass. Here Come Google Contacts," (Nextgov, October 14, 2015, http://www.nextgov.com/mobile/2015/10/forget-google-glass-here-comes-google-contacts/122793/, accessed October 17, 2015).
[91] Ibid.

information from various objects within a user's FOV.[92] Should this technology come to fruition, it would create the most symbiotic relationship yet between AR digital information and a user.

In summary, the range of commercially viable AR smart-glasses has never been larger. Their form factors and use-cases range widely from inconspicuous, light-weight glasses to bulky head-mounted visors. Some are meant for niche markets such as elite sports performance monitoring and industrial maintenance aids; others are intended for broader audiences. As varied as these products and their uses are, they share similarities in their fundamental engineering. The following section describes a generic AR system architecture that many AR systems employ.

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[92] Ibid.

How Augmented Reality Systems Work

Augmented reality systems encode detailed information about a user's environment and their actions there within. Data inputs from the environment provide information to AR mapping applications that encode details about a user's surroundings and the locations of objects within space. This mapping data helps generate a virtual map that the AR system will later use to anchor virtual content in 2D and 3D perspectives. In addition to building a virtual map, these data inputs can also be used by other AR applications. Some AR applications can perform object recognition. For example, the retail sector has invested heavily in developing such applications so it can enhance the shopping experience of customers.[93] Once an object is recognized in retail setting, this data can cue enhancing information such as the name of the object, its price, or perhaps reviews of the object. In a similar manner, AR object recognition can identify people, and in the near future may be able to link this information to online profiles and social media data.

Beyond object identification, another central task of AR systems is to track the precise location of their users within an environment. This user location data provides the AR system's virtual mapping application a reference point from which to present virtual information back to the user. The most advanced AR systems also precisely measure the head location of their users as well as the direction of their visual gaze. With this data, AR systems can render 3D virtual information, anchored to a user's perspective within a given environment. For instance, this is how Microsoft's HoloLens can allow users to attach virtual content frames, such as virtual televisions, virtual news feeds, and virtual teleconferences, to real-world surfaces and then move

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[93] Lance Eliot, "Retail's New Reality: Invisible Shopping Centers and Virtual Assistants," (CNBC, April 24, 2015, http://www.cnbc.com/2015/04/24/, accessed October 17, 2015).

about in space and retain a realistic experience due to corresponding updates in the geo-spatial perspectives of these digital frames of content. These digital frames appear to remain in place as a HoloLens user moves about. They see virtual televisions on walls when in reality nothing is there. To perform the complex tasks of cueing digital content and rendering it appropriately, a number of subcomponents comprise an AR system. The following section offers a generic model of these subcomponents and how they interact that captures the essence of most AR systems.

Figure 1 Generic Augmented Reality System Architecture

Types of Sensors

The entry points for data into an augmented reality system are sensors resident in the AR display device or relayed to it. Similar to the developments from sensor-fusion in smartphones, AR display devices are also experiencing a revolution in new applications meant to leverage their built-in capabilities. For AR systems, however, digitized sensor data's most important

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function is to provide coordinate information about users, their environments, and objects in space. This information is used to help capture information about a user's environment and to later help render virtual content back into a user's FOV on their AR display device. Sensors collect various forms of analog data from an environment and then digitize it. Once this analog data is collected and digitized, it can be combined across sensor types in a process known as sensor-fusion. This fusion of information is essential for high-quality AR experiences.[94] Today, AR systems use a wide variety of sensors to include the following.

Optical Cameras. Digital optical cameras use an electronic sensor, typically a complementary metal-oxide semiconductor (CMOS) or charge coupled device (CCD) to capture images. The lens on an optical camera focuses the light onto the electronic sensor. The optical properties of the lenses change the focus of the camera. The size of its aperture determines the amount of light that can enter the lens. Most AR systems rely on at least one optical camera.

Depth Camera. Normally, depth-sensing cameras would require multiple visual inputs. However, new single lens depth cameras combine new LEDs arrays and machine learning to register depth. These new depth-sensing cameras have been produced largely to capture user's hand motions and gestures as inputs to control AR interactions with virtual content.

Infrared Camera. Infrared cameras use an electronic sensor to capture infrared radiation. Infrared radiation is radiant electromagnetic energy invisible to the human eye with a frequency range from 700 nanometers to 1 mm. Infrared cameras offer two unique applications for AR systems. First, they provide another robust means of capturing data from an environment to build a virtual map of one's surroundings. When paired with infrared markers, they can be used to identify marked objects invisible to the human visual system. In this way, AR developers that

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[94] J.D. Hol, T.B. Sch¨on, F. Gustafsson, and P.J. Slycke, "Sensor fusion for augmented Reality," (In International Conference on Information Fusion, Florence, Italy, August 2006).

craft AR experiences can declutter a visual environment, and still provide their systems easily identifiable markers that do not require robust ambiguous object discrimination capabilities.

Accelerometers measure g-force acceleration. They typically are employed in motion sensing applications to continuously calculate changes in one's position. Beyond navigation applications they have also been incorporated in biometric applications that seek to measure the body-movement of users. In addition, smartphones and mobile devices use them to indicate changes in screen orientation so they can trigger portrait and landscape views.

Magnetometers measures the magnetization of material and in some cases the direction of the magnetic field at a point in space. In mobile devices, and AR systems, magnetometers typically serve as compasses along three-axis. They have also been used to track changes in the magnetic field of users. This information can be used to identify gestures and controls.

Solid-State Compasses. A solid-state compass determines direction relative to the earth surface for navigational purposes. These compasses rely on two or three magnetometers and a microprocessor to calculate heading.

Global Positioning System (GPS) Receiver. GPS receivers collect cell-tower and space-based navigational information about one's location, as well as timing cues. Cell-tower GPS receivers determine location based on signal measurement strength, and timing to receive GPS signals from surrounding towers and then calculate a user's location based on triangulation methods. Space-based GPS receivers use radio waves from space, using the same general methods as cell-tower GPS receivers, to determine a user's location.

Gyroscopes. Mobile devices and AR systems use gyroscopes to calculate orientation and rotation. They have been incorporated to measure movement within 3D space. When combined with accelerometers, they can accurately calculate changes along 3-axis.

Barometers. In mobile devices barometers help GPS receivers to get a faster lock by providing altitude data instantaneously.

Pressure Sensors. Pressure sensors measure the ambient air pressure. These measurements can be used to measure altitude by using the pressure difference between two locations. These type of sensors are typically used in touchscreen technologies.

Proximity Sensors. Proximity sensors in mobile devices can detect when a phone is brought to a user's face during a call. Most mobile devices use infrared proximity sensors so they can reduce display power use by turning off the LCD and disabling the touch-screen during phone calls.

Radio-Frequency Identification (RFID). RFID uses wireless electromagnetic fields to transmit and receive data. This technology is typically used to automatically identify and track tags or markers attached to objects.

Bluetooth. Another wireless technology used to transmit and receive data over short distances is Bluetooth. Bluetooth uses UHF radio waves in the ISM band that ranges from 2.4 to 2.485 GHz. Many AR systems use Bluetooth to transfer data to AR display devices from a separate AR component that houses the central augmented reality processor and various AR modules.

Wi-Fi. Wi-Fi provides a local area wireless networking capability. Data is transferred typically at the 2.4 GHz and 5 GHz frequency radio bands. Similar to Bluetooth, AR utilizes Wi-Fi connections to communicate data to and from AR systems holistically and to particular wireless AR display devices.

Microphone. Microphones capture acoustic data and transform it to a digital format through an acoustic-to-electric transducer or sensor. In AR systems, built-in microphones can register a user's commands as well as other sounds from a user's environments.

Capturing and Tracking Modules

AR capturing modules combine sensor information with geo-locational 3D coordinate information to provide geo-registered data about a user's environment. As sensors digitize an AR user's environment, they identify markers that will be referenced later to anchor virtual information. Capturing modules use sensor-specific reference points to link this anchoring information to raw sensor data. This information is then used to render virtual information.

Tracking modules use the anchoring information provided by the capturing module as a means to track the locations of a user's augmented reality device and objects from the real environment. AR systems use tracking modules to add virtual objects into a user's perception of the real-world. The geo-location of the AR device and the markers created by the capturing module serve as the basic elements used to orient information within the virtual environment. As AR users move throughout an environment, the tracking module continuously reregisters their position and the relative position of objects in both real and virtual environments. This allows AR systems to fix the location of virtual objects and keep them oriented correctly in response to an AR user's real-time movements in space.

Currently, AR systems vary in how they capture and track reference points and anchor digital content. Some rely on simple pattern recognition of basic shapes and markers. In these systems, when a pattern is recognized an AR system will replace that area with virtual

information.[95] For example, a wall in a room may be registered as a reference point and used to anchor a virtual monitor on it. When an AR user looks toward the blank wall while wearing an AR display device the virtual monitor will appear.

Another method employed by AR systems to capture and anchor information is the outline method. This technique recognizes different parts of an AR user's body, such as the hands or face, and then tracks the movements of these parts so AR users can interact with virtual objects using natural movements.[96] For instance, when an AR user reaches for a virtual object and makes a grasping motion, this action can trigger a protocol that can move and rotate the virtual object in 3D space. In this manner, AR users can interact with virtual objects. Furthermore, simple hand gestures may be used in the way that swipes, pinches, and taps control smartphones and tablets today – though instead of touching a physical surface these motions could take place in space. Microsoft has already developed these types of controls for their Kinetic system and they will likely be employed in HoloLens.

The location method utilizes detailed GPS or triangulation methods to precisely overlay and orient digital content relative to an AR user's location.[97] When discrete shapes and surfaces are not readily available, such as in natural landscapes, simply knowing the precise locations of objects through GPS sensors, can allow for the tracking and display of virtual information. For military forces accustomed to monitoring blue forces as icons on 2D screens, this information can now be projected in AR displays in 3D real-world environments. An operator on patrol can look over a valley and see virtual icons, displayed to represent depth and distance, of blue forces in space. The same is true for marked targets and known areas of interest. They can all have

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[95] Kipper and Rampolla, *Augmented Reality: An Emerging Technologies Guide to AR.* (2013).
[96] Ibid.
[97] Ibid.

virtual content associated with them so that when the time comes when an AR user comes within range that enhancing information can appear overlaid on that location.

Finally, the surface method uses surfaces, walls, and screens that respond to touch to display virtual content. As users touch and interact these two dimensional surfaces they can manipulate and interact with virtual objects.[98] ARES has created an AR sand table whereby users can interact with virtually displayed earth and objects and manipulate their locations through hand gestures that correspond to how someone would naturally build a sand table today.[99] The acts of pushing, scooping, pulling virtual content immediately renders changes in these virtual images as if they were real objects.

Some, but not all, AR systems combine aspects from each of these four types of capturing models. The more advanced systems track user's actions, and captured detailed information about environments, so they can render virtual content in a manner that best deceives the human sensory/perceptual system from distinguishing the virtual from the real. As sensors decrease in cost, and increase in capacity, the accuracy of all AR capturing modules will increase. At the same time as the power of capturing models increases and their ability to identify and recognize objects expands – the catalogue of virtual AR experiences will only expand and become more powerful.[100]

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[98] Ibid.

[99] Hope Hodge Seck, "Microsoft's Kinect Aids in 'Augmented Reality Sand' Mapping Tool for Marines, Army," (ArmyTimes, September 23, 2014, http://archive.armytimes.com/article/20140923/NEWS04/309230074/Microsoft-s-Kinect-aids-augmented-reality-sand-mapping-tool-Marines-Army, accessed October 24, 2015).

[100] Aviva Rutkin, "Computers are Learning to See the World Like We Do," (New Scientist, October 19, 2014, https://www.newscientist.com/article/mg22429932-300-computers-are-learning-to-see-the-world-like-we-do/, accessed October 10, 2015).

Virtual Information

Virtual information comes from augmented reality applications and is then rendered in the AR display device. Multiple AR applications may run at the same time providing unique content in a hybrid manner. This information can be rendered in either two or three dimensions using one of the four capturing methods previously described (pattern, outline, location, or surface). The majority of all advertised AR systems can render 2D enhancing information. This is sometimes described as mediated reality. The content is not necessarily anchored to a person's perspective. If they move their head the AR data remains fixed in their FOV. This does not mean the data itself is not tailored to the environment or the user's experience in it.

The more complex AR virtual information, and the data that most would define as true augmented reality, is that which appears overlaid and anchored to discrete locations within a user's real-world environment. For example, AR users may experience 3D virtual-telepresence whereby an offsite co-worker appears seated at a conference table in the same room as the AR user. They may also see 3D rendered blue prints and schematics they designed projected in real space. They can move around these virtual objects and examine them from new angles. On the future site of a building, an architect may see a virtual building and have the capability to add or remove structures in the order in which they will be constructed. In the military, particularly in the Navy, having this type of capability would be of great benefit. Virtual information about new additions to a vessel could be projected inside a vessel for engineers to better visualize how they would appear and fit within existing structures.

Augmented reality devices may have multiple software applications running and displayed for users. The information used and presented by these various AR applications may come from various sources. Aside from the AR content tailored to the specific AR system, future

AR systems will likely incorporate other third-party AR applications. Currently, Microsoft's HoloLens will run Windows 10, and as such it will be able to load and run any application compatible with this operating system. Soon, AR users may open their email program, cable news feed, social media application and attach this virtual content to various walls and surfaces in their office and leave them running as they move in and out of that space.

Virtual information may originate from processing at the AR display-device or it may come from content servers accessed through a mobile internet connection. By originating at the AR display device the latency to present rendered information decreases; thereby, increasing the responsiveness of these AR systems. However, as AR services begin to enter commercial markets, more digital AR content and out-sourced processing may reside away from the AR display device. Information from external data sources such as Wiki-like content servers and social media sites will inevitably have to be stored elsewhere and accessed dynamically. The characteristics of how AR virtual information is presented are determined by the AR rendering module.

Rendering Module

Rendering modules combine information from a real environment with virtual information. They operate within and are controlled by an AR system's Centralized Augmented Reality Processor (CARP). Rendering modules take an AR application's virtual information and prepare it to be presented back to the user. They utilize what can be thought of as a virtual camera, identical to the cameras found at the AR display device, to prepare virtual objects to be displayed in a convincing manner. They use the geo-locational 3D coordinate information provided by the tracking module to place information in a virtual 3D rendition of a user's real environment. Once placed, the rendering module takes the 2D and 3D virtual information

injected by the AR applications and makes it appear at the proper locations, in the correct size, shape, and orientation for the user's AR device display.

Centralized Augmented Reality Processor (CARP)

The CARP serves as the primary control mechanism within AR systems. Much like a Central Processing Unit (CPU) controls the overall actions of computers the CARP coordinates the actions of AR systems. It is the digital brain of AR systems. It transmits sensor inputs and manages processing resources shared by the capturing, tracking, and rendering modules. It also provides processing and memory resources for any AR application running at the AR device while also receiving corresponding virtual information from external AR applications via its mobile internetwork interface. Finally, it prioritizes and organizes virtual information to be rendered and projected by the AR display-device.

Display Devices

As previously noted, a number of different AR display-devices exist. These display-devices come in many form factors and will continue to evolve to become lighter and less obtrusive as their sub-components decrease in size and increase in capability. The earliest forms were HUDs and HMDs. Both of these can either use optical see-through or video see-through. The growth of smartphone and tablets generated AR applications that simply displayed AR content using their displays. In a similar manner TV displays and kiosks can present AR rendered virtual information. As previously outlined, much of the current excitement about the future of AR systems, however, has arisen out of the growing capability of AR glasses and contact lenses. As these devices decrease in size and become less conspicuous they will attract more users.

Augmented Reality and Enhanced Cognition

The previous sections discussed the development AR technologies and briefly described some of their current capabilities. The following section will explore how AR systems will affect human cognition. As an information technology, AR systems affect how their users gain information and understand it. What makes AR revolutionary is that it will also redefine how its users explore and interact with their environments. The use of AR systems affects basic elements of cognition, such as how attention is directed and maintained. In addition, they also affect more complex cognitive activities such the integration of new information into mental representations and frameworks.

Human thought can be understood as a continuous perception-action cycle. This cycle consists of flows of sensory signals through specialized regions of the brain organized to process discrete forms of information. This processing identifies patterns in order to develop predictive cuing and these flows of information develop circuits from the senses to higher-level cognitive processes that guide goal-directed behavior.[101] Signals from sensory organs follow discrete paths, both to higher level processing centers as well as to primitive, reflexive mental nodes. Primitive mental functions, which require little goal-directed control, allow humans to respond automatically to various stimuli. Higher level mental functions, process and organize incoming information and distribute it to other mental nodes for processing. These higher level mental functions do not only receive signal information for processing but they also direct lower level sensory/perceptual actions. They do this through the control of a central executive that allocates

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[101] Vassilis Cutsuridis, Amir Hussain and John G. Taylor (eds): "Perception–action Cycle. Models, Architectures, and Hardware," (Cognitive Neurodynamics, Vol. 5, Issue 4, November, 2011), pp. 411-412.

attention and working memory.[102] This is how humans can quickly move from watching a football game, to listening to and encoding details about a story someone is telling, and then return back to the game and still recall both the progress on the football field as well as details from the narrative.

The central executive is a top-down cognitive mechanism. The sensory/perceptual feeds to the brain are bottom-up cognitive mechanisms. Both sub-systems have limits and constraints.[103] Many often complain that they wished they had better memories, or that they could better focus. AR systems may be able to assist or impede both functions depending on their design. Understanding not only how attention is captured but also how it is controlled is central to understanding precisely how AR devices impact both top-down as well as bottom-up cognitive processing.

Augmented Reality and Sensory/Perceptual Experiences

By their nature, AR devices capture and redirect AR users' attention. Attention serves as both a "filter" for bottom-up processing, restricting noise and registering signals, and a "fuel" for top-down processing providing mental focus.[104] Particularly salient stimuli in an environment can automatically capture one's attention. The idiosyncratic needs of an organism, combined with its particular sense organs, determine what is salient and what is not.[105] The smell of a female dog in heat may not register for most human pet owners, but it sure attracts the attention of their dogs.

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[102] A.D. Baddeley & G. Hitch, "Working Memory," (In G.H. Bower (Ed.), *The Psychology of Learning and Motivation: Advances in Research and Theory*, Vol. 8, Academy Press, NY), pp. 47-89.

[103] George A. Miller, "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information," (Psychological Review, 63, (2), 1956), pp. 81–97.

[104] Christopher D. Wickens, "Attention," (In John D. Lee & Alex Kirlik (Eds.) *The Oxford Handbook of Cognitive Engineering*, 2013), pp. 37-56.

[105] David Oderberg, *Perceptual Relativism,* (Philosophia, 16, 1-9, 1986).

Of the five primary senses in humans, the visual system tends to dominate sensory experiences and the direction of attention. A flash of light, sudden appearance of an object, or rapid movement automatically captures human visual attention and causes one's gaze to fixate on the source of the salient events.[106] In an earlier time in humankind's history, these events may have indicated the presence of a predator to be avoided or an opportunity during a hunt. Today, the human visual system is still tuned to these types of salient cues. Augmented reality display devices naturally capture the attention of their users because they introduce these types of onsets and cues. Therefore, the first very basic way in which AR systems will change how their users experience their worlds is by automatically redirecting their visual attention.

Beyond their visual displays many AR systems also include auditory outputs. Some of the basic auditory outputs simply provide for 2D sound experiences. Users can hear sounds and language either in mono or stereo formats. In more advanced AR systems, auditory information is presented in a manner that gives the illusion of coming from 3D space. These outputs are designed to give the illusion of sounds coming naturally from one's environment.[107] Combining 3D sounds with dynamic visual AR content creates a multi-modal sensory experience that further increases the verisimilitude of the AR experience for users.

In addition, AR wearables exist that interact with a user's haptic sensory/perceptual experiences. They vibrate and pulse based on external cues.[108] In this manner, they can give the illusion of physical contact and interaction with virtual objects. For example, researchers at Disney created an AR tactile technology that generates the same haptic experience of feeling real

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[106] Ran Carmi and Laurent Itti, "Visual Causees Versus Correlates of Attentional Selection in Dynamic Scenes," (Vision Research, 46, 2006), pp. 4333-4345.

[107] William Shankin, "Microsoft HoloLens: An AR Headset That Makes You see 3D Holograms in Your Living Room," (Gizmag, January 21, 2015, http://www.gizmag.com/microsoft-hololens-details/35708/, accessed May 15, 2015).

[108] Olivier Bau and Ivan Poupyrev, "REVEL: Tactile Feedback Technology for Augmented Reality," (ACM Transactions on Graphics, Vol. 31, No. 4, Article 89, 2012).

objects by creating an oscillating electrical field around a user's fingers. When users reached for, and interacted with virtual objects, they reported experiencing the same type of haptic sensations as when they interacted with real items and materials.[109]

Beyond affecting these basic, bottom-up sensory/perceptual experiences, AR systems also affect other fundamental forms of cognition such as spatial perception and reasoning. When humans navigate, they rarely have to devote a lot of top-down attention. Various bottom-up cognitive faculties allow humans to navigate to and from locations and remain oriented with an environment. The use of AR systems provides additional spatial cues and navigational aids to assist AR users to know their location and maintain their desired direction of travel. At times when the human spatial perception system struggles, such as when visibility is limited, or in environments where reliable spatial cues are occluded or obstructed, AR systems can provide the necessary means to remain oriented. AR systems can achieve this by displaying simple directional arrows or geo-registering a target destination and displaying it in a user's FOV.

In summary, it is clear that the use of AR systems impacts human sensory/perceptual experiences by tricking the human mind into believing that virtual content is real. Augmented reality systems can present realistic signals, primarily through the visual and auditory systems, but also in new haptic apparatuses. In so doing, AR systems can capture and redirect the attention of their users. This bottom-up signaling can thus force users to focus on virtual information over the real-world. The challenge for AR system designers is to recognize just how distracting these devices can be. They must put in place appropriate safety measures to ensure users do not pay more attention to digital signals than real-world dangers.

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[109] Ibid.

Augmented Reality and Information Behavior

Beyond affecting bottom-up sensory/perceptual experiences AR will also have a profound effect on top-down cognitive processes – in particular those that comprise the behavior employed in learning. AR systems will transform the way in which people interpret and explore their environments. They will alter how they seek out information and use it. By employing AR systems throughout their daily lives, users will grow accustomed to the many ways in which AR will change their information behavior. To explain the catalogue of these effects the following sections will use David Ellis's descriptions of key human information behaviors.

Starting when people begin to look for new information they employ predictable patterns of information seeking behavior. In general, people begin by looking for sources of expertise (i.e. a subject matter expert, relevant books or publications, or online search.[110] The relative background knowledge of the individual looking to learn combined with their particular learning style affects their approach. However, most begin by looking for a credible reference. After the birth of the internet, sources of expertise shifted. With the expansion of AR systems, connected not only to the internet, but also cloud processing and virtual personal assistants, another shift in credible references will occur. More people will turn to Facebook's M, Apple's Siri, Microsoft's Cortana, and Google Now for answers before talking to a real person or visiting a library. What AR systems provide is continuous access to these information sources and a new symbiosis between the question asker and the answer giver.

Those wearing AR devices will gain the ability to share their AR sensor data with semi-artificial intelligent services – thereby letting the Siris of the future to not only hear voice commands but also "see" an AR user's digitized surroundings. From this, dramatic changes in

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[110] David Ellis, *The Derivation of a Behavioral Model for Information Retrieval System Design*, (Doctoral Thesis submitted at University of Sheffield, August, 1987).

how humans start to look for information will ensue. In a not too distant future, these services may begin to anticipate the questions their users will generate to an even greater extent than they already can.[111] They may use geo-referenced data to offer up insights and recommendations based on one's location, time of day, or registered biometric state. For example, when an AR user's system registers a drop in blood sugar at a time when they are near a series of restaurants, it may automatically offer suggestions for recommended restaurants it predicts a user may ask about. Or, if an AR system registers a rare word, or unusual term used by someone addressing an AR user, it may display a definition in their FOV to reference. Already today, real-time translation software is present in Google Glass, thereby allowing it to translate foreign conversations for its users. Currently, AR systems do not have any direct links to such semi-artificial intelligent services, but many can connect to the internet both receiving and sending information. This two-way data flow will increase learning for both AR systems and AR services looking to understand the behavior of their users.

Chaining. The next action most people take as they begin to seek out information is to link new information with the old.[112] This is what is known as chaining. As people learn more about a given subject they often look for other source materials used to frame the information or support a claim. They compare new information with what they already know and determine if it fits in their current understanding, or somehow alters it.[113] AR systems can facilitate this process. AR systems allow users to gain enhancing, explanatory information in real-time. This differs from smartphones and computers that require users to shift their attention away from their current environment or perspective in order to interact with various search engines.

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[111] PRWeb, "Deep Learning and Digital Companions are the New Virtual Assistants," (Virtual Strategy Magazine, October 24, 2015, http://www.virtual-strategy.com/2015/10/24/deep-learning-and-digital-companions-are-new-virtual-assistants#axzz3pUT0RmRL, accessed October 24, 2015).
[112] Ellis, 1987.
[113] Ibid.

AR systems enable users to better understand and visualize the relationships between various forms of information by helping them to rapidly access relevant explanatory information. For example, AR systems have been employed in several maintenance tasks. For example, BMW has developed an AR system its mechanics can where that displays virtual information about its cars' engines.[114] Mechanics can use AR systems to not only see virtual configurations of systems so they can better identify unknown parts, but they can rapidly retrieve additional information about these unknown components through a voice directed search engine. They no longer have to look away from the task at hand while seeking to expand their understanding or solve a particular problem. At the same time, if they wish to pause what they are doing, and learn more about other factors related to a given problem, they can rapidly access further enhancing information. In this manner, they are able to chain the information they discover.

Searching. Browsing concerns information behavior involving semi-directed or semi-structured searches for information.[115] Though inefficient at times, browsing allows people to quickly scan a list of contents and select what items may be of interest.[116] To date, RSS feeds and the ability to "follow" a person or organization allow users to automatically receive collections of information on topic areas in which someone is particularly interested. In the future, AR systems will reduce the time to find relevant information by learning what browsing patterns its users employ and what particularly content is of most interest to them. With this data, AR can begin to predict what information a user may need or want in a given environment or when faced with a particular type of problem.

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[114] Victoria Woollaston, "End of the Mechanic? BMW Smart Glasses Make it Possible for ANYONE to Spot and Fix a Car Engine Fault Just by Looking at it," (Daily Mail, January 21, 2014, http://www.dailymail.co.uk/sciencetech/article-2543395/The-end-mechanic-Smart-glasses-make-possible-fix-car-engine-just-looking-it.html, accessed October 17, 2015).
[115] Ellis, 1987.
[116] Ibid.

AR systems can first achieve this through geo-fencing techniques that cue virtual information. Geo-fencing involves pairing digital information and content with real-world, geographical boundaries. Geo-fencing applications have been designed for various entertainment and tour services. For example, when customers visit various wineries they automatically receive alerts and details about the wineries wines via their mobile devices.[117] A number of commercial retailers are looking to employ similar geo-fencing techniques so that potential customers only get notifications when they are within range of one of their products in a store. Through AR systems, geo-fencing would not only affect how people browse for information in digital spaces but also how they interact with objects in their real-world environments.

Another means by which AR can affect browsing is by monitoring where people direct their attention. A number of AR display devices tracking head and eye movements so they can render virtual content in the correct position and orientation relative to a user's FOV. This same data, however, can be used to track what objects, people, and locations gain a user's attention. When an AR system has this data, it can then begin to automatically search for enhancing information and present it if desired to the AR user. Through this type of tracking, future AR systems will affect how people browse and search their environments.

Differentiating. As people seek out information they prefer to gain new knowledge from trusted sources. Differentiating is the information behavior concerned with the credibility and quality of a given source of information.[118] Future AR systems will impact this information behavior in a couple of significant ways. First, through the use of the afore-mentioned semi-artificial intelligence services such as M, Siri, Cortana, Google Now, etc., AR users may drift

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[117] Shel Israel, "How VinTank is Building a Geo-Fence Around Wine Country," (Forbes, March 20, 2013, http://www.forbes.com/sites/shelisrael/2013/03/20/how-vintank-is-building-a-geo-fence-around-wine-country/, accessed October 17, 2015.
[118] Ellis, 1987.

away from trusting human expertise to relying on computer-aided understanding to a greater extent. In addition, AR systems may display rating and review indicators of people that users interact with.

To the extent that future AR systems can recognize people that come within range of an AR user's optical cameras and then look up their level of expertise, or reputation through an online database, they could then offer some form of indication to an AR user. For instance, when speaking with an electrician an AR user may see a star indicator, such as four stars out of five, displayed as a semi-transparent halo floating over their head. From this enhancing information, the AR user would automatically know that previous clients thought highly of their performance. Similar to what online customers today can see when reviewing potential products or services, future interactions with others may trigger AR systems to present various indicators about a person's expertise, credibility, reputation, etc.

Extracting. As people learn new information they try to focus on what is important to them while filtering out other distracting details. Extracting is concerned with selectively drawing only the information most relevant to a user at a given time.[119] Identifying what sources of information are most useful is a pre-requisite of any extraction effort. The increase in semi-artificial intelligent personal assistant services combined with AR's ability to learn from a user's continuous interaction with various sources of information across a variety of environments will allow AR systems to better present the most relevant information for its users. As AR systems gain access to object recognition applications and services they will be empowered to rapidly identify and categorize items in one's surroundings and thereby help prioritize what should be attended to.

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[119] Ellis, 1987.

The impact of AR use on how users extract information could take many forms. Some users may become solely reliant on their AR systems to feed them information. Those less inquisitive may be satisfied with an AR system's default search results. Other AR users may demand more of their systems and will spend more time finding ways to rapidly learn all there is to know about a particular setting, situation, object, or person. Some AR systems may be dominated by marketing applications and consequently inundate their users with focused advertisements. Still others may be specialized for niche professions such as doctors and scientists –the virtual information of these particular systems may cost a great detail or require restrictive licensing or service contracts. Only time will tell precisely how AR systems determine what information to extract and present to their users. Regardless, these systems will have an impact on where their users direct their attention and how they extract information from their environments.

Verifying. A particularly valuable application of AR systems in human information behavior will come in the form of verification of information. Verifying simply refers to checking the accuracy of the information.[120] Augmented reality systems can provide real-time fact checking. They can offer up counter evidence or arguments as a user is viewing or listening to various sources of information. By employing AR verification tools, the claims of experts could be questioned. The advertisements of marketers could be checked. AR systems could provide a continuous monitor for lies and false claims. This could be one of the greatest impacts of AR systems on how users interact with others and their environment.

Verifying in a commercial terms could be visualizing how an article of clothing might fit or whether a piece of furniture would look in a room. Already today, these types of AR applications exist. Customers can use AR fitting kiosks to display an article of clothing virtually

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[120] Ellis, 1987.

and then compare how it would look on them. Likewise, using a smartphone or tablet prospective furniture shoppers can view on their device how a piece of furniture would fit in a given space by pointing the optical camera of their device toward the region of interest. In this manner, AR systems can better help their users visualize and verify information.

In summary, the use of AR systems will revolutionize how humans learn and seek out new information. The growing symbiosis between humankind and technology will only accelerate when the barriers to interaction fade away. With AR devices that capture the same sensory signals that their users experience, various AR applications will begin to tailor the delivery of useful, enhancing information to their users. Furthermore, the more AR users interact with AR systems, the more these systems will understand their users unique needs and desires. AR systems will thus provide the next iterative step in closing the distance between the real-world and digital domains. They will decrease the time it takes to access digital information and they will increase the amount of data available to both AR users and AR digital services.

Augmented Reality and Decision-making

The use of AR systems will not only impact a user's sensory/perceptual experiences and change how they seek out and use information, it will also affect how AR users make decisions. Cognitive researchers have concluded that two discrete systems exist in the human mind that shape decision-making. One is based on intuition the other on deliberate analysis.[121] These distinct systems have been labeled *System 1* and *System 2*. System 1 is fast, instinctual, heuristic based, and emotionally driven. It is the default means of making decisions. It requires the least effort and is very efficient. System 2, in comparison, is slow, deliberate, and rational. It is needed

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[121] Daniel Kahneman, *Thinking, Fast and Slow.* (Farrar, Straus and Giroux, 2013). See also K. E. Stanovhich and R. F. West, "Individual Differences in Reasoning: Implications for the Rationality Debate," (*Behavioral & Brain Sciences* 645-665, 2000).

in unfamiliar situations and is used to solve complex problems.[122] Augmented reality systems will affect both reflexive and deliberate forms of decision-making.

As previously discussed, AR systems will first shape both systems of decision-making through its effects on sensory/perceptual experiences and information behavior. The greatest potential impact of AR on decision-making, however, could come in its users increasing dependence on AR systems to guide their decision-making. These effects can be understood by considering how dependent most smartphone users have become on their device's navigational applications. Before GPS devices and smartphones, people developed navigational skills, and made decisions while traveling based on a set of environmental signals. They used System 1 to respond to rapidly changing environmental cues and they relied upon System 2 to make deliberations when confronted with ambiguous navigational information. Today, navigation applications on smartphones draw drivers' attention away from their environment and traditional navigational indicators. Through smartphones, directions are presented on 2D digital maps that update a user's location and generate directions as they travel. Drivers no longer have to pay close attention to environmental markers. Nor do they have to reason about their route. They follow a set of cues with little cognitive effort. It is highly likely that other tasks that require intense focus and concentration for decisions will be outsourced to automated decision-making aids found in future AR systems.

Augmented reality systems will change System 1 decision-making by modifying the heuristics System 1 uses to base its decisions. Heuristics allow users to quickly categorize a situation and make judgments based on their previous experiences.[123] They allow for quick,

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[122] William Duggan, *Coup D'Oeil: Strategic Intuition in Army Planning, (*Army Strategic Studies Institute, 2005).

[123] Gary A. Klein, "Naturalistic Decision-making," (*Human Factors*, Vol. 50, Issue 3, 2008), pp. 456-460.

effective decisions but they can also lead to cognitive biases.[124] Just as the use of smartphone navigational applications caused travelers to attend to alerts on their mobile devices versus road signs in their environment so too will AR systems shift users' attention away from other cues in their environment upon which they once relied to make rapid decisions.

Augmented reality systems will have an even greater impact on System 2 decision-making. To the extent that AR users desire to make more rational, logical decisions, AR systems can search out and present them with information and perspectives to help them make a determination. Augmented reality systems, connected to the internal and other external data sources, can fill gaps in its users' knowledge and understanding. The ever-growing body of collective knowledge found over the internet, ever available to AR users, will provide a reservoir of knowledge from which to draw. Furthermore, the ability of AR systems to adapt to the idiosyncratic information behavior and preferred leering style will permit them to present information in a manner most beneficial to sound reasoning and intelligence decision-making. There may come a time where AR users fear making a significant decision without their AR device as much as they fear traveling to a new city today without their smartphone.

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[124] Daniel Kahneman and Amos Tversky, "Judgment Under Uncertainty: Heuristics and Biases." (*Science* 1124-1131, 1974). See also Raymond A. Nickerson, "Confirmation Bias: A Ubiquitous Phenomenon in Many Guises." *Review of General Psychology,* 1998) pp. 175-220. As well as D. Kahneman, A.B. Krueger, D Schkade, N Schwarz, and AA Stone, "Would You be Happier if You Were Richer? A Focusing Illusion," (*Science* 2006), pp. 1908-1910. And also A. Tversky and D. Kahneman, "The Framing of Decisions and the Psychology of Choice," (*Science,* 1981), pp. 453-458.

Augmented Reality Applied at the Tactical Level

The following section will consider specific applications of AR technologies at the tactical level of operations in the military. Building on the previous discussions of the effects of AR on users' attention and its impacts on learning and decision-making, this section will explore some of the existing tactical use-cases of AR systems as well as future potential use-cases. The first tactical use-case most relevant to the military concerns tactical combat operations.

During a tactical engagement, AR systems can increase the speed at which forces can orient toward an adversary and apply a weapon system. They can improve one's chances during combats competitive decision-making cycle. John Boyd's theoretical model, which coined the term O-O-D-A Loop, describes this process. According to Boyd, in tactical engagements, operators first observe what is going on around them.[125] They then orient this information and set of circumstances to situations with which they are most familiar. To do this they rely on top-down cognitive processes such as long-term memories.[126] After processing this information, operators then make a decision and either act or react.[127] After this action the cycle begins again. AR systems can improve each of these stages.

Observation and Orientation

Augmented reality systems can aid in tactical observation. They can achieve this by receiving feeds from sensors on the battlefield and by providing their own sensor inputs back into these systems. In today's military philosophy of network centric warfare, all combat systems share information to and from the battlefield. Armed with this information, combat forces can

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[125] John Boyd, "Organic Design for Command and Control," (*Airpower Australia.* May. Accessed May 15, 2015. http://www.ausairpower.net/JRB/c&c.pdf, 1987).
[126] Ibid.
[127] Ibid.

decide whether to move toward an enemy or remain outside of the effective ranges of their weapon systems. Fixating a target is the first essential task in achieving information superiority over an adversary and AR systems offer the next expansion of information technologies capable of benefiting this requirement.

In tactical environments combat forces not only seek to observe enemy targets they also wish to remain aware of friendly forces and civilians within a given operating area. The "fog of war" makes it difficult to keep track of all of these forces concurrently. By displaying the known locations of friendly forces and civilian areas of interest AR systems aid their users in maintain their situational awareness. As AR users move throughout an environment, whether by land, air, or sea, AR systems can continuously display and update this targeting information to direct engagements and avoid collateral damage and fratricide.

Tactical Situational Awareness

As combat forces move through a tactical environment they continuously seek to gain and maintain SA. Augmented reality systems can help combat forces to gain and maintain Tactical SA more effectively by continuously registering information from their surroundings and combining it with external virtual information provided by various battlefield management and intelligence systems. In this manner, AR can increase the information superiority for combat forces.

Battlefield management systems integrate various sources of combat data based on the operational functions concerning command and control (C2), movement and maneuver (M2), fires, intelligence, sustainment, and protection. Most battlefield management systems provided automated reporting and standardized geographical overlays to help present a common operating picture (COP) to tactical and operational level units. They are meant to aid targeting and

decision-making cycles. AR systems can leverage their data repositories while simultaneously providing real-time inputs during combat operations. Access to this information should make combat forces more effective and more efficient at closing with and defeating an adversary.

Navigation and Maneuver

As operators move throughout an environment they must continually remain oriented to their surroundings while attempting to find the most effective path to their tactical objective. Augmented reality applications have demonstrated they can aid navigation.[128] They can provide enhanced information about a user's location and provide real-time directions by overlaying directional cues on one's FOV. As previously described, AR navigational applications aid the underlying spatial cognitive cues required for navigation, such as cues for orientation, location, and direction.

A number of AR navigational applications for navigation already exist. GPS enabled map services provided by Google and Apple on most smartphones represents a profound AR aid for wayfinding. In tactical settings, the ability to use these core systems with specific intelligence produced overlays that represent the previous passage of friendly units or historical threats would allow small-units to plan their routes to minimize the predictability of their movements and avoid threats. Beyond tactical mapping software that provide similar capabilities, AR can present this information in real-time, projected over a given area, so that its users can maintain better SA of this data and better envision their environments.

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[128] Mehdi Mekni and Andre Lemieux, "Augmented Reality: Applications, Challenges, and Future Trends," (Applied Computer Science, 2011), pp. 205-214.

Targeting and Fires

Augmented reality systems can also help combat forces in the precise targeting of both direct and indirect fires. The employment of combat weapons systems requires accurate aim and controlled fire. Once an enemy target is observed and fixed combat forces then seek to apply the right military means to achieve their tactical objective. AR systems can recommend weapons of choice and in the future they may be integrated with the actual firing mechanisms of combat systems. For example, just as the F-35 helmet links into fire control systems in the F-35, some day HMDs worn by ground forces may communicate with vehicle mounted weapon systems.

Augmented reality systems can help operators achieve their tactical objectives by helping guide lethal and non-lethal effects onto a target. In combat operations most assume that operators would simply seek to destroy the target, but there are a number of scenarios in which an operator would rather neutralize, disrupt, or simply deny an adversary the use of a given target. Depending on the nature of the combat system, the AR display device may be able to demonstrate what the potential effect of that system may be on the surrounding area before a given munition is selected. This in turn may help combat forces save rounds, and reduce unintended effects. In addition, using AR guiding mechanisms for "smart weapons," combat forces may achieve levels of accuracy in fires previously reserved for guided missile systems. Smart weapons can tag targets and share this information with one another. The scopes on these systems also include sensors that can collect imagery and ballistic information. The U.S. Army is rumored to have recently begun testing current smart rifles with the goal of fielding them in the near future.[129] The use of AR systems to guide these direct fire systems at the small-unit level,

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[129] Brendan McGarry, "U.S. Military Begins Testing 'Smart' Rifles," (DefenseTech, January 15, 2014, http://defensetech.org/2014/01/15/u-s-military-begins-testing-smart-rifles/, accessed October 17, 2015).

combined with its ability to guide indirect fires platforms could provide an unprecedented level of target discrimination and accuracy.

Enhanced Understanding

Beyond helping combat forces gain tactical SA and better target an adversary, the use of AR in combat environments will help combat forces better understand their environments and the people and objects with which they interact. AR will achieve this by providing explanatory information about locations, objects, and individuals to which its users attend. A variety of AR developers have begun to introduce this type of enhancing capability. For example, one AR device already in use provides enhancing information based on what is being displayed on a user's TV screen. SeeSpaces's InAIR, AR software layers additional content from the internet and social media in either 2D or 3D formats based on the content being shown. Through this process viewers can learn extra details about products and people that appear in a television production. Similarly, Layar's AR software provides enhancing digital content to generate interactive print. Layar users witness enhancing virtual content as they interact and engage with traditional print and other forms of commercial packaging.

Beyond providing enhancing information to digital and print media, AR software developers have also engineered a number of retail AR applications that provide explanatory information for users as they move through environments and interact with objects. Retailers hope to not only attract patrons to their stores through the use of augmented reality, but they also want to leverage this technology to increase their sales.[130] To do this, they have begun to adapt AR to improve the shopping experience of their customers both in stores and at home. They have

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[130] Philipp Spreer & Katrin Kallweit, "Augmented Reality in Retail: Assessing the Acceptance and Potential for Multimedia Product Presentation at PoS," (SOP Transactions on Marketing Research, Vol 1., No. 1, May 2014), pp. 23-31.

introduced virtual fitting rooms, AR advertising, AR product previews and enhanced product information at the point of sale.[131] AR applications exist that will provide wiki-type content near an object or location in order to provide a potential customer more information about a given store or its product.[132]

Beyond these early AR applications, mostly developed for specific commercial clients and tailored to provide vendor generated content, next generation AR applications will employ advanced recognition software to identify and then search for user specified enhancing information. Object recognition is one of the technical challenges currently limiting AR.[133] However, the ability of visual recognition processing applications to identify objects in an environment from multiple angles and under degraded environment conditions is increasing.[134]

As additional capabilities to provide enhancing information appear in commercial AR systems AR technologies will be made available for military use. A tactical AR user today might be able to look along a city-street and see virtual information detailing the names of city streets, building names, and key landmarks. Soon, military data sources may be generated to provide information about sources for cover and concealment, or information detailing historical intelligence reports about a given area. One useful feature already present in some AR systems is the ability to have an X-Ray type view where an AR user can see buildings and other environmental information that is occluded by other objects projected virtually.[135] This information helps combat forces, as well as first responders, to navigate through man-made

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[131] Philipp Spreer & Katrin Kallweit, "Augmented Reality in Retail: Assessing the Acceptance and Potential for Multimedia Product Presentation at PoS," (2014).
[132] Ibid.
[133] Kipper and Rampolla, *Augmented Reality: An Emerging Technologies Guide to AR.* (2013). See also Ihsan Rabbi, Sehat Ullah, and Siffat Ullah Khan, "Augmented Reality Tracking Techniques: A Systematic Literature Review Protocol," (IOSR Journal of Computer Engineering (IOSRJCE), Vol. 2, (2), 2012), pp. 22-29.
[134] David Randall, "Army Heads Up Situational Awareness Technologies," (MILCOM Presentation, October 26, 2015).
[135] Livingston et al., "Military Applications of Augmented Reality," (2013).

structures. As more commercial AR applications such as these come to market they will make their way into military settings.

Biometrics and Emotional Intelligence

The use of AR technologies to expand the range of human sensation and perception is one of the more exciting and potentially disturbing uses of AR. Currently, sensors on some AR systems, like the Microsoft HoloLens can detect and identify facial expressions and even detect changes in skin temperature and heart rate.[136] The depth camera employed by HoloLens can interpret this data and use it to predict the mood of anyone the AR user looks at.[137] For those that suffer from a distinct ability to detect the emotional states of others this type of technology could become essential. It also has the potential to serve as a real-time lie-detector system capable of interpreting the body language, facial expressions, and autonomic nervous system responses to discover a person's physiological "tells".

Augmented reality systems can also register other biometric information and then use this information to identify individuals and call forth any available enhancing information about them. Before long, AR cameras and sensors will be able to go beyond simple facial recognition and soon be able to identify more distinct biological markers such as iris distinctions and finger prints from a distance. Individuals will either be identified in real-time or selectively registered. If registered, their unique biometric markers will be automatically uploaded and linked to meta-information such the location and nature of their enrollment. Once the use of AR technologies become adopted widely it will be very difficult for individuals to remain anonymous.

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[136] Mark Hachman, "Microsoft Patents Mood-Sensing Tech for the HoloLens Augmented-Reality Headset," (PCWorld, April 28, 2015, http://www.pcworld.com/article/2915861/microsoft-patents-mood-sensing-tech-for-the-hololens-augmented-reality-headset.html, accessed July 20, 2015).
[137] Ibid.

Maintenance and Technical Help

Virtual telepresence and remote collaboration are other practical uses of augmented reality. Remote collaboration involves two or more people working on the same task using a computer to mediate communication and interaction.[138] Users of this type of AR system can share a view of their work space with one another. The value of this capability increases particularly when specialists are few in number and high in demand. Through telepresence and remote collaboration, AR can provide the means to increase access to expertise.

The field witnessing the strongest motivation to adopt AR is medicine. The limited number of medical specialists combined with the desire to simultaneously visualize medical data and a patient in the same space are primary drivers of advances in AR medical systems.[139] AR affords doctors the ability to watch procedures remotely and then project their responses back into the FOV of an onsite technician. Other specialized technicians can leverage AR's ability to provide remote assistance. For example, Microsoft's recently announced Holo device demonstrated a vignette in which a plumber walked a customer through replacing a drain pipe on her bathroom sink. The customer not only saw a VTC image of the plumber projected in her FOV, but the plumber also could render a virtual 3D diagram in the customer's visual perception of her bathroom which directed her how to properly install the given pipe.

The use of AR systems for maintenance and engineering applications has also received a lot of attention. This is due in large part to the use of systems produced by large manufacturing

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[138] Matthew Tait, Tony Tsai, Nobuchika Sakata, Mark Binnghurst, Elina Vartiainen, "A Projected Augmented Reality System for Remote Collaboration," (Presentation at IEEE International Symposium on Mixed and Augmented Reality, Adelaide, Australia, October 1-4, 2013).
[139] Mekni and Lemieux, "Augmented Reality: Applications, Challenges, and Future Trends," (2011).

companies like Boeing, Lockheed Martin, BAE, BMW, and Caterpillar amongst many others.[140]

Mechanics, engineers, and assembly line operators employ AR devices to guide their interaction

with various parts and components.[141] Rather than having to look away from their work to

reference a manual they see AR overlays in their FOV. Tests conducted to determine the benefits

of using AR devices reveal that engineers worked up to 30 percent faster with accuracy at nearly

96 percent.[142] Military mechanics and engineers in each of the services could benefit from such

tools. Naval engineers working throughout a ship could be able to not only see virtual descriptors

of existing systems they could also gain the ability to see through the walls and view future

mechanical installations. Likewise, vehicle mechanics could diagnose engine problems more

rapidly and complete repairs more efficiently if they had the help from a virtual personal AR

assistant.

In tactical settings, an operator's ability to interact with a remote technician in real-time

could dramatically increase their effectiveness. AR could provide an operator to see the

directions of a subject matter expert virtual presented in his FOV thereby increase his

understanding dramatically and improve the likelihood he could complete a given task for which

he had little or no previous training. If an operator had to treat a casualty he could call upon a

remote doctor to guide his application of first aid. Field mechanics that used to hunt through

technical manuals could have subject matter experts provide directions through 3D virtual

gestures and instructions. One can imagine a scenario out of a typical Hollywood action film in

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[140] Sarah A. Webster, "The Fourth Industrial Revolution – It's Here," (Huff Post, September 25, 2015, http://www.huffingtonpost.com/sarah-webster/the-fourth-industrial-rev_b_8196006.html, accessed October 24, 2015).
[141] Wayne Grayson, "How Caterpillar is Developing Virtual and Augmented Reality to Design and Service Heavy Equipment", (Equipment World, October 22, 2015, http://www.equipmentworld.com/how-caterpillar-is-developing-virtual-and-augmented-reality-to-design-and-service-heavy-equipment-videos/, accessed October 24, 2015).
[142] Alexander George, "Lockheed is Using These Augmented Reality Glasses to Build Fighter Jets," (Popular Mechanics, February 6, 2015, http://www.popularmechanics.com/flight/a13967/lockheed-martin-augmented-reality-f-35/, accessed October 17, 2015).

which an operator could be shown virtually which wire to cut on an explosive device while a team of EOD experts thousands of miles away guide him through his AR device. Through the use of AR technologies, the U.S. military in general could begin to centralize its various communities of expertise and then distribute this knowledge to the edge of the battlefield through various AR applications developed to create a virtual tele-experience.

Piloting and Robotics

As noted during the introduction to AR technologies HUDs have been used by pilots for decades. All military vehicle operators face the challenges of maintain oriented to their environment as they attempt to navigate and maneuver. Well-designed AR applications can provide this navigational information, while also providing information useful to help vehicle operators and their crew maintain their SA. For example, pilots of the USMC AH-1Z and Joint Strike Fighter and soon Mini-Cooper drivers, can see through the skin of the vehicles with AR devices. By inputting live video captured from external vehicle cameras, these systems provide pilots increased awareness of objects in their environment.

Augmented reality can also be used to interact with and control robotic and unmanned systems. Medical and manufacturing robots have long been used with AR devices and applications.[143] Robots have typically been controlled tele-operationally with a user relying on visual cues from the robot's perspective. Users have a difficult time, however, maintaining SA using this method. Researchers, therefore, have begun to explore the ability of multimodal AR interfaces to increase performance in a user's ability to control robotic devices. Their results

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[143] Paul Milgrim, Shumin Zhai, David Drascic, Julius J. Grodski, "Applications for Augmented Reality for Human-Robot Communication," (Proceedings of the 1993 IEEE/RSJ International Conference on Intelligent Robots and Systems, Yokohama, Japan, July 26-20, 1993).

have found AR spatial cues benefit users' accuracy and speed in controlling robotic devices.[144]

Augmented reality appears ready to provide the next generation control system for robotic

technologies and unmanned systems, both incredible growth industries.

Training and Education

The first use case for Augmented Reality systems in the military that has gained any

significant attention has come from the training opportunities these systems provide. A handful

of research groups, such as the Navy Research Lab, have invested research and development

efforts to test the value of use AR systems as training aids.[145] The value of AR systems as

training aids is due to the practical advantages they provide. Virtual information can be

combined with existing live-action training facilities to reduce changes to infrastructure

requirements and demands for human role players. Virtual enemy targets can be displayed in

realistic 3D depictions. These avatars can then be easily reprogrammed to interact in novel ways

so that trainees can run through live-action training exercises numerous times.

The Marine Corps recently announced it has developed an AR training system called

Augmented Immersive Team Trainer (AITT).[146] This system allows marines to train on directing

airstrikes and calls-for indirect fire.[147] Typically this type of training requires intense

coordination for military assets and costs a lot due to the expense of these types of munitions. By

providing realistic training scenarios, AR systems such as AITT can reduce these costs and

increase opportunities for combat forces to increase their proficiency in complex tactical tasks.

[144] Scott A. Green, J. Geoffrey Chase, XiaoQi Chen, Mark Billinghurst, "Evaluating the Augmented Reality Human-Robot Collaboration System," (International Journal of Intelligent Systems Technologies and Applications, Vol. 8, 2010), pp. 130-143.

[145] Livingston et al., "Military Applications of Augmented Reality," (2013).

[146] Sydney J. Freedberg, "Marines Explore 'Augmented Reality'," (Breaking Defense, September 1, 2015, http://breakingdefense.com/2015/09/marines-explore-augmented-reality-training/, accessed October 24, 2015).

[147] Ibid.

Challenges and Recommendations for Adopting AR Technologies at the Tactical Level

As beneficial as AR systems may before for actions taken at the tactical level, there are a number of challenges that will have to be overcome before any military accepts their whole-sale use. Issues concerning safe-use practices are a primary concern. In addition, certain technical limitations in AR systems currently exist that may create some hesitancy in procurement. Lastly, a handful of social issues, privacy concerns, and unique security concerns of the military will have to be addressed before AR systems are allowed within the ranks of any branch of service.

Distraction

Balancing the level of distraction of AR technologies will be a fundamental challenge and consideration in the evolution of AR system designs and control features.[148] Augmented reality systems can automatically capture the attention of their users by presenting particularly salient signals and cues within their FOV. As was noted in the previous discussion concerning the impacts of AR systems on sensory/perceptual experiences, these signals can generate distractions a user may not be able to avoid.

To overcome the potential safety issues that could result from AR systems distractors the first step should be the development of built-in safety measures. The systems should have automatic kill-switches that disable the presentation of any distracting information both manually and automatically in times of great distress. In addition, AR systems designers should refer to references, such as the *Oxford Handbook for Cognitive Engineering*, that provide recommended best practices in system design that take into account how the human mind functions. Finally,

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[148] Kipper and Rampolla, *Augmented Reality: An Emerging Technologies Guide to AR.* (2013)

future AR systems should themselves offer alerts and warnings to their users when a danger appears and take actions to focus a user on responding to such situations.

Sensor Range and Accuracy

A technical limitation of current AR systems is the range and accuracy of their intrinsic sensors. To the extent that these sensors are used to collect environment data their sensitivity will impact the quality of later AR processing, and rendered virtual information. Bad data in leads to bad data out. In tactical military settings this may have grave effects.

Fortunately, sensors, like micro-processors, appear to be following the same development path predicted by Moore's Law. Nearly every 18 to 24 months, they gain increased sensitivity and accuracy, while decreasing in size, cost, and energy consumption. For military AR systems developers and engineers, this means that the current semi-bulky, non-ruggedized, large-energy consumers may transform into much smaller, much lighter, more rugged, sustainable systems.

Connectivity at the Edge of the Battlefield

One limiting factor for AR system performance in combat operations is their access to external data sources. Connectivity to the edge of the battlefield remains a central problem for Signal planners across all branches of service. Over the past two decades, as the military has operated in regions with little or no internet connectivity, they have engineered systems that can now allow them to provide internet connectivity to deployed forces. The terminus for these links typically resided on large forward operating bases with static satellite terminal sites. This started to change after 2010, however.

Today, more systems have been fielded that provide reach-back connectivity both through line-of-site and beyond-line-of-site data links. These forward deployed tactical networks

can be leveraged by tactical AR systems. Through secure wireless links, AR systems can push and pull data across these systems. The remaining question will concern where does do the military AR data services reside. If they stored in a CONUS location then the fragility of the data link, its bandwidth, and latency, could greatly impact deployed AR experiences. If these data sources can be incorporated into forward deployed battle management systems, then these challenges would be overcome. Future programs of record for a Joint AR system should take these factors into consideration in their design.

Social Challenges, Privacy, and Data Security

Perhaps the greatest limiting factors to the adoption of AR systems within the military are social challenges, privacy concerns, and unique security classification of military information. The introduction of a new technology like AR can disrupt social norms. When Google introduced its AR devices in public settings many of its users experienced strong backlashes from others.[149] Many see AR display devices as barriers to interaction and forms and social distractors. Others are concerned about their privacy due to the cameras on these devices that record and register AR users' surroundings.[150]

Military personnel will inevitably share these concerns, but they also have to manage information that may be sensitive or classified. A key question for future military AR system designers is how to turn on and off the collection of AR sensor data, and how to selectively classify it. For example, data from a combat engagement may need to be restricted, but data about geographical features, locations of infrastructure, etc. may be useful for less sensitive data services. A system that does not classify all sensor data in a bulk manner may increase the utility

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[149] Anisse Gross, "What's the Problem with Google Glass?" (The New Yorker, March 4, 2014).
[150] Ibid.

of future AR systems. Furthermore, future AR system designers will have to deal with the

challenging issues of securing AR data-at-rest and the potential loss or compromise of these

devices. Programs exist already for mobile devices and laptops that can effectively erase

sensitive data if it falls into the wrong hands. Any viable military AR system will have to do the

same.

Augmented Reality Applied at the Operational Level

The majority of proposed and tested use-cases for AR systems have focused on their tactical level applications. In reality, AR systems may be used in military office spaces and conference rooms well before they are fielded to tactical combat forces. The reason for this, is that many of these systems are being designed to increase individual productivity, creativity, and collaborative ability. In addition, because the military requires much higher standards for performance of information technology systems designed for use in harsh tactical environments its more likely the military will begin to use AR systems in Garrison first. Therefore, the following section will explore some of the ways AR systems will alter and benefit operational level planning and decision-making.

The U.S. military's doctrine for planning recognizes that operational planners rely on both crisis response planning as well as more deliberate efforts.[151] In crises action planning (CAP), operational staffs use the collective experience and knowledge of their planning team to develop courses of action rapidly. During deliberate planning, they spend greater time researching viable course of action and seeking outside expertise. As previously discussed, AR systems can benefit the fundamental decision-making processes behind both intuitive and deliberate planning. Beyond improving these forms of operational decision-making, however, AR can also benefit operationally command and control through improved operational situational awareness, better visualization tools, and improved means of providing virtual presence and communication.

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[151] Karol G. Ross, Gary A. Klein, Peter Thunholm, John F. Schmitt, and Holly C. Baxter, "The Recognition-Primed Decision Model," (*Military Review* 6-11, 2004).

Situational Awareness and Understanding

Augmented reality systems can improve SA and understanding through their ability to integrate multiple sources of information to generate a common operating picture and then share this picture through various battlefield management systems. In order to plan and make decisions regarding the employment of tactical forces operational leaders must understand and monitor the Operational Factors of Space, Time, and Force. They need to understand and visualize how these factors interact with, and affect their forces and their adversaries' forces. In addition, they must remain aware of the relative combat potential of these forces – typically through indicators across the six Operational Functions (i.e. C2, Movement and Maneuver, Fires, Intel, Protection, and Sustainment). Operational leaders use their understanding of these elements to respond in times of crisis and to plan deliberately. By monitoring AR COP applications, an operational leader can stay abreast of any significant changes in these elements.

Augmented reality systems allows users to see virtual representations of forces, with indicators of combat readiness, projected over either real environments or digitally rendered common-operating-pictures (COP). With an AR display device, an operational leader, whether they are in their office, state room, the DFAC, or out on the battlefield can witness the precise location and movement of both friendly and enemy forces. On the battlefield, these indicators may influence a commander's understanding of how a battle is progressing. For example, a commander may see virtual lines moving as tactical forces gain and lose territory. They may see progress on the field of battle the same way that viewers see AR first-down lines shift on televised football games today. These AR overlays provide both audience the means to see quickly where their team is at and how much further they have to go.

Augmented reality systems also increase SA by providing real-time updates and alerts to operational leaders. As battle management systems collect information and updates, they can rapidly disseminate this information through AR systems. An operational leader's continuous access to information about the availability, readiness, capability, and capacity of tactical forces allows him to determine if they are near culmination or not. This can increase response times to deploy reserve forces or to provide medical support. Likewise, the combined running estimates of an enemy situation informs operational leaders how close tactical forces are to achieving victory. The increased fidelity, timeliness, and relevance of the information provided by AR systems to operational leaders will enable them to better direct their forces.

Another way that operational leaders will benefit will come through the nature of the enhancing, explanatory information military AR systems may soon provide. Future battle update briefs in which an intelligence analyst refers to a particular enemy target may trigger an operational leaders AR system to display enhancing information about the targets ethnic affiliation, known associates, and last registered location. This access to enhancing information will speed up the sharing of information and increase the understanding of operational leaders and their staffs.

As beneficial as it is for operational leaders to gain access to better information and continuous SA updates, the ability of AR systems to adapt to their users' learning preferences will prove even more significant. As was previously noted, AR systems will begin to modify how they guide their users to information once they learn their preferred information sources and learning styles. In addition, they will likely vary the aperture of their search based on a user's available timeframe to process it. In this manner, these systems will create a more adaptive user experience.

Visualization and Operational Design

After operational leaders understand their operational environment and the particular problem they face they begin to develop plans. They start by formulating a desired end-state and then they visualize various courses of actions. They typically apply aspects of both operational design and art to develop a lines of operation focused on achieving a desired objective.[152] The use of AR systems can benefit operational planners as they work through these processes.

First, operational leaders can use AR systems to help them visualize possible courses of action. In the same manner that AR systems are already helping engineers and manufacturers visualize their conceptions, so too can they help operational leaders see how the employment of tactical forces would take place in both time and space.[153] For example, 3D CAD renderings allow engineers and architects to experience diagrams virtually in 3D and to scale.[154] Operational leaders could leverage future battlefield management systems to generate similar virtual renderings of their operational plans. These renderings could then be displayed in AR sand-tables, such as that developed by ARES systems, or perhaps projected in space while wearing an AR display device. For example, in the future, an operational commander afforded the opportunity to conduct an in-person reconnaissance form the vantage of a flying platform could use an AR system to virtual project tactical forces and visualize how various tactical encounters might play out.

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[152] JCS, JP 3-0, 2011.

[153] Rana Abboud, "Architecture in an Age of Augmented Reality: Opportunities and Obstacles for Mobile AR in Design, Construction, and Post-Completion," (2014).

[154] Anthony Webster, Steven Feiner, Blair MacIntyre, William Massie, and Theodore Krueger. n.d. *Augmented Reality in Architectural Construction, Inspection, and Renovation,* (Accessed February 14, 2015. http://www.columbia.edu/cu/gsapp/BT/RESEARCH/PAPERS/ar-asce.html).

Describing for a Shared Vision

After operational leaders have developed an operational plan they then must communicate it. Augmented reality systems can help operational leaders share their understanding and proposed tactical actions. In coordinating up, down, and between organizations and agencies, operational leaders must address a number of audiences. [155] Augmented reality can help in this effort by accessing and display data from battlefield managements systems to help present and organize information in a meaningful way. Just as smartphones and mobile devices are keeping leaders better connected to each other, and information, so too will AR systems enhance the communication of shared visions.

Augmented reality can aid communication and increase shared understanding by creating and maintaining virtual collaborative environments controlled by next generation battlefield management systems. The benefit of AR systems, is that they provide timely access and updates to these systems both in garrison and tactical environments. There is no delay in the upload. Tactical units to not have to return to the forward operating base to generate and update a field report. This report can be generated in real-time, and shared, through the use of AR systems. Through this real-time updating, AR systems can provide a continuously updated common virtual operating picture. A number of battlefield management systems currently exist that could be modified or integrated with future AR technologies. This will facilitate greater information sharing and collaboration to and from tactical objectives which would in turn facilitate increased collaboration and self-synchronization. The realization of AR systems employed both at the

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[155] HQDA, *ADP 5-0*, 2012.

tactical and operational levels would move military operations closer to the network centric

warfare philosophy of power-to-the-edge.[156]

Direction and Leading

Augmented reality systems could also benefit operational leaders in their efforts to direct

and lead forces both in garrison and in combat. Regardless of the information technologies

available, Operational commanders must describe their intent, establish achievable objectives,

and issue clear tasks and guidance.[157] Augmented reality systems would make operational

leaders more effective and efficient in these tasks. This in turn would allow them to respond

more quickly and remain more agile. In combat, controlling the pace of operations is integral a

combat force's success.[158] U.S. military forces desire to *operate at the speed of the problem*.[159]

AR can increase an operational leader's ability to maintain a relative speed advantage in

directing and leading forces – particularly those forces that have come to rely upon precision

guided, highly synchronized operations to defeat high-tech adversaries.

Increasing the speed at which operational leaders can make decisions does little without

also providing the means to implement them. During combat, changes to intent and objectives

must be rapidly disseminated. Due to the ability of AR systems to continuously receive alerts to

update a user, they can dramatically reduce the time it takes to notify key leaders and personnel

of changes. The use of AR systems allows remote users to share and communicate information.

For example, distant operators could share their sensor information so that an operational center

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[156] Alberts, *The Agility Advantage,* (2011).
[157] HQDA, ADP 5-0, 2012.
[158] JCS, JF-2020, 2012.
[159] Dempsey, 2012.

could see first-hand footage of an engagement.[160] This is just another form of virtual

telepresence. At the same time, AR systems provide traditional voice communications and

instant messaging applications.

Throughout all phases of planning and combat operations the presence of leaders matters.

Face-to-face interactions, and direct understanding, increases cohesion and develops trust within

organizations.[161] Some have argued that the use information technologies has caused leaders to

distance themselves. Much of this, however, may be accounted for by the increased demands

placed on all leaders to remain always connected.[162] With the advent of AR systems, leaders

could still maintain an eye on various notifications of interest, but they would not have to remain

tethered to the computer in their office. Augmented reality systems can help leaders interact with

their teammates without worrying about missing any time-sensitive information.

Assessing

As operations unfold, operational leaders must continuously assess the situation. They

must anticipate and adapt operational plans to changing conditions.[163] Operational leaders are

expected to continuously measure the overall effectiveness of the actions of their tactical

forces.[164] Through instant updates from the edge of the battlefield, and increased outputs from

deployed AR sensors, operational leaders can gain better assessments of tactical actions.

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[160] Shenai, M.B., M Dillavou, C. Shum, D. Ross, R.S. Tubbs, A. Shih, and B.L. Guthrie, "Virtual Interactive Presence and Augmented Reality (VIPAR) for Remote Surgical Assistance." (Neurosurgery, Vol. 68, 2011), pp. 200-207.

[161] Stephen M.R. Covey, *The Speed of Trust : The One Thing that Changes Everything.* (New York: Free Press, 2008).

[162] Nicholas Bloom, Luis Garicano, Raffaella Sadun, and John Ven Reenan, The Distinct Effects of Information Technology and Communication, (CEP Discussion Paper No 927, London: Center for Economic Performance, London School of Economics and Political Science, 2009).

[163] HQDA, ADP 5-0, 2012.

[164] JCS, JP 3-30, 2014.

The most important impact of AR systems in improving the ability of operational leaders to assess operations is from their production of timely information. However, other features of AR systems may better enable operational leaders to understand changes to an operational environment or forces. For example, abstract variables in a complex adaptive system, such as public sentiment, rates of violence, and perceived threats may be more concretely visualized and analyzed through the use of AR's 3D graphical representations. Future AR representations of complex battlefield elements may help operational leaders to understanding these interacting dynamics. Various AR systems' use of concrete images and representations to explain complex topics has already been demonstrated to aid learning - particularly when the information is abstract or difficult to imagine.[165]

Finally, through their access to big-data analytical tools, AR systems will provide users powerful real-time analytical aids. Big-data analytics are used today to comb through vast amounts of data to discover patterns and hidden trends. Future AR systems will not only have access to repositories of collected data but will also likely contribute their own data to these collections. Every AR user will be a sensor. Therefore, the actions of AR users will also be analyzed and become their own measures of effectiveness.

Challenges and Recommendations for Adopting AR Technologies at the Operational Level

The challenges of adopting AR systems at the operational level build upon the concerns raised at the tactical level. However, some of the concerns differ based on cultural differences between tactical operators and operational leaders and their staffs. At the tactical level, AR systems can transform many manual tasks and alter how people directly interact with their

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[165] Mehmet Kesim, and Yasin Ozarslan, "Augmented Reality in Education: Current Technologies and the Potential for Education." (*Procedia - Social and Behavioral Sciences* 297-302, 2012).

environments. At the operational level, the use of AR systems will serve as an expansion of the capabilities found in today's IT productivity suites and battlefield management systems. The following concerns may overlap with some of the tactical challenges of adopting AR systems, but perhaps fit more of the central issues of integrating AR systems at the operational level.

Anti-Technology Biases

The first challenge to overcome in adopting AR technologies within operational level staffs and organizations will be overcoming anti-technology cultural biases. Most operational leaders and their staffs are more senior in rank and age to tactical level operators. As such, they will typically be lest accustomed to, and comfortable with new information technologies. At the operational level, leaders that choose to adopt AR systems will have to be aware that many organizations suffer from an anti-technology bias among various groups of employees.[166] For example, when the concept of Network Centric Warfare was introduced in 1999, many high-profile military leaders resisted the notion that the Information Age would significantly alter how the U.S. military functioned.[167] As a result, they were slow to anticipate the changes information technologies would play on combat operations and make the necessary strategic investments to fully exploit these transformations.

If organizations do not co-evolve their structure, processes, and policies to fully leverage advancements in information technologies they incur an enormous opportunity-cost.[168] The introduction of AR systems will require the military to reassess and restructure its organization, practices, and doctrine. The military should begin to educate its leaders and service personnel of the capabilities and opportunities of AR systems now so they can fully take advantage of them

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[166] Karl D. Schubert, *CIO Survival Guide: The Roles and Responsibilities of the Chief Information Officer,* (John and Wiley Sons, 2005).
[167] Alberts, *The Agility Advantage,* (2011). .
[168] Ibid.

once they arrive within their ranks. If the military fails to anticipate the sea-change this technology will have on humankind in general, it will not take the prerequisite steps to plan for and build the infrastructure necessary to make full use of AR's capabilities.

<u>Information Overload</u>

A concern at the operational level is that AR users will become overwhelmed by the amount of information available to them.[169] Information overload can occur when too much information is available and is not well-organized.[170] As some seek out more and more information they can begin to hesitate to act. They will wait until the last piece of evidence can be obtained.[171] As operational leaders become accustomed to ever present streams of real-time, enhancing information, they may experience paralysis-by-analysis.

As concerning as information overload may be, the fundamental purpose behind AR systems is to focus a user's attention to relevant information. Great IT systems are designed to provide essential information in an intuitive manner.[172] If the military hopes to prevent information overload it should begin by specifying requirements for future AR systems that can help ensure AR systems prevent distraction and information overload. Additionally, through training and education, operational leaders and their staffs can learn to integrate AR systems into their decision-making processes in a manner meant to mitigate the potential for information overload.

An Over Dependence on Augmented Reality

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[169] Thomas P.M. Barnett, "The Seven Deadly Sins of Network-Centric Warfare," (*Proceedings Magazine,* 1999).

[170] Milan Vego, *Joint Operational Warfare: Theory and Practice.* (Govt Printing Office, 2009).

[171] Alan Zimm, "Human-Centric Warfare." (*Proceedings*, Vol 125, No. 5, May, 1999).

[172] Laura G. Militello, and Gary Klein, "Decision-Centered Design." (In *The Oxford Handbook of Cognitive Engineering*, by John D. Lee and Alex Kirlik, 261-271. New York: Oxford University Press, 2013).

Another concern is that decision makers will become overly dependent on AR systems after they grow accustomed to their continuous interaction with these systems. Today, many have become addicted to information technologies. Most would rather leave home without their wallets than without their mobile devices.[173] Operational leaders that begin to lose their ability to make sound decisions without the help from information technologies may struggle when they lose access to these systems. For example, if an adversary disrupted, denied, or destroyed access to these information systems they may gain a distinct advantage over future AR dependent militaries.

As concerning as an over dependence on information technologies may be, organizations should not avoid integrating technologies that may offer them an advantage simply because they fear someday losing access to them. Leaders at all levels must manage this risk and develop means to mitigate it by developing redundancy and alternative means of commanding and controlling their forces. As new disruptive technologies appear it's the leader's place to determine how best to leverage their capabilities as well as manage the new risks that emerge after their adoption.

Fears of Micromanagement

Perhaps the greatest fear of many within the military is that the proliferation of information technologies has led to greater micromanagement by senior leaders.[174] In fact, some believe the call for *mission command* by senior military leaders is meant to address the growing concern that leaders, at all levels, abuse the capabilities of new C4ISR systems to increase their

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[173] Meena H. Duerson, "We're Addicted to Our Phones: 84% Worldwide Say They Couldn't Go a Single Day Without Their Mobile Device in Their Hand*,"* (2012).

[174] Robert Bolia, Michael Vidulich, Todd Nelson, and Malcolm Cook, "A History Lesson on the Use of Technology to Support Military Decision-making and Command and Control," (In *Decision-making in complex environments*, by Malcolm Cook, Janet M Noyes and Yvonne (Eds.) Masakowski, Aldershot: Ashgate, 2007), pp. 191-201.

access and influence on the actions of their subordinate units.[175] Introducing AR systems at the

tactical and operational levels has the potential to heighten these fears. The use of AR systems

represents a further extension of information technologies into the daily lives and activities of

service personnel. Therefore some will resist their use.

Micromanagement is a people problem – not a technology problem. Regardless of the

technologies available, some leaders trust their subordinates others do not. Rather than viewing

AR as a threat to autonomy, it should be conceived of as a means to flatten organizations so that

greater unity of effort and shared understanding can take place.

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[175] P.W. Singer, "Tactical Generals: Leaders, Technology, and the Perils of Battlefield Micromanagement," (*Air & Space Power Journal*, 2009).

<center>**Discussion and Recommendations**</center>

Though the military will have to overcome some unique challenges associated with integrating AR into its ranks the benefits of adopting AR far out way the costs. Augmented reality systems have demonstrated that they have reached a commercial tipping point. Soon, consumers will begin to purchase and use them throughout their daily lives. From this, greater demand signals will be placed on planners within the military to leverage the capabilities of AR systems. The following set of recommendations are offered to help planners prepare for this inevitability.

Recommendation 1 – Anticipate Back-end Infrastructure Requirements and Policy Changes

In order to take full advantage of the potential of AR systems the military should not wait for commercial sectors to fully mature before sharing its requirements and shaping future AR developments. The military should begin to capture its unique needs and communicate these to its defense industry partners in order to realize fully, the maximum potential of AR systems. It will not be enough to procure these systems and distribute them to units. A significant investment in developing the requisite back-end infrastructure to support these new sources of data and information flow must take place. In addition, the military will have to reconsider many of its policies, particularly as they relate to data classification, security, and access. Leaders will have to determine where risk resides and decide if combat forces are being hamstrung by outdated, overly risk averse policies that prevent them from fully leveraging emerging information technologies such as AR.

Recommendation 2 – Develop a Holistic AR Data Management Plan

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Any augmented reality system is only as good as the virtual information it provides. As the military plans for and investing in future battlefield management systems it should consider what information will be of most use to military AR users. It should also consider what information will come from military AR users. In addition, the military should demand that these sources of information are capable of being input into other C4ISR applications regardless of manufacturer. The growth of big-data analytics, super-computers, and semi-artificial intelligent personal assistants is only going to increase. Military personnel will desire to leverage these services as much, if not more than commercial entities. Therefore, the military must lead an effort to ensure that AR data remains open-source, interoperable, and standardized.

Recommendation 3 – Intuitive and Rugged

Military AR systems must be intuitive to use and designed for rugged use. They should be designed to elegantly present only the information that enhances a user's perceptual experience. They should deliver simple means for decision-making and increase a user's ability to communicate and share information. They should not be a computer monitor mounted to a helmet. Augmented reality systems cannot become distractions or difficult to operate or they will be discarded quickly. The military, and its defense industry partners, should take a note from corporations like Apple devote as much time in engineering elegant interfaces as they do in writing software code. At the same time, the same set of AR glasses that a service member uses in an office setting will not hold up in the field. Any additional piece of kit worn in combat must be lightweight, rugged, and unobtrusive. These systems should replace a required piece of equipment if at all possible. For example, tactical AR systems should replace required eye-protection as well as other optics such as night-vision or thermal lenses. Combat forces should not have to swap between multiple pairs of glasses if it can be avoided.

Recommendation 4 – New Organization Structures and Military Occupations

Finally, the military should begin to plan for the changes in organizational structure, processes, and doctrine that will occur after the proliferation of AR systems within the ranks of the military. The military must consider how to transform its force structure to prepare for the introduction of AR systems. Augmented reality is not just another smart-device on the battlefield. It is a means to transform how the military gathers information, analyzes its operating environment, makes decisions, and collaborates across the farthest edges of an operating environment. The ultimate ability of AR to bring about the increased combat effectiveness it promises will result from a new generation of Soldiers, Sailors, Marines, and Airmen embracing its potential and tailoring its capabilities to their needs. Their training, their resources, and their attitudes will be decisive in determining AR's future. Whole new ways of conducting daily military activities, and conducting large-scale combat operations, will have to be developed throughout all echelons, if the military wants to make full use of the range of possibilities future AR systems will present.

Conclusion

Augmented reality technologies have matured to a point that they are ready to transition to large-scale commercial adoption. Over the next five to ten years, the use of AR systems will fundamentally change how users interact with each other and their environment. Access to AR systems will alter how AR users perceive their surroundings and learn new information. The growth of AR systems in the consumer market will increase calls for its adoption within the ranks of the military. Many will discover that many civilian AR uses-cases overlap with military requirements. As such, now is the time to begin considering, and preparing for the use of AR systems within the ranks of all branches of service.

For combat forces at the tactical level, access to AR information will provide a decided advantage in their ability to observe, fix, and finish targets. At the same time, AR will provide combat forces better situational awareness and access to control measures to help limit fratricide and collateral damage. The use of AR systems also has the potential to improve decision-making. For operational leaders, AR can provide new means to understand, visual, and describe complex problems and environments. It can also help operational leaders direct their forces and assess the effectiveness of their actions. Adopting AR systems at both the tactical and operational levels will have its challenges. However, failing to integrate this revolutionary technology will cost the U.S military its decision-making advantage and jeopardize its ability to achieve information superiority over its adversaries.

The U.S. military must adopt augmented reality (AR) technologies at the tactical and operational levels or risk losing a decision-making advantage to its adversaries. Augmented reality systems represent a revolution in information technologies. As such, they offer the next iterative advance in Network Centric Warfare capabilities that the U.S. military should exploit.

Augmented reality systems can ensure U.S. forces maintain their information superiority

advantage throughout this next revolution in information technology.